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"THE EFFECT OF LOW TEMPERATURE ON THE STRENGTH OF CONCRETE"

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

by

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Edmonton Alberta

April 1961

A B S T R A C T

A testing program consisting of compression tests on 650 three inch diameter by six inch concrete cylinders and flexural tests on 300 three inch by three inch by eighteen inch concrete beams was conducted. Cylinders and beams were molded from three mix designs and tested after curing under standard conditions for periods of 7 days, 28 days, 2 months, and 4 months. Prior to testing, specimens were subjected to predetermined conditioning temperatures ranging from $+70^{\circ}$ F to -30° F. Determinations were made of the ultimate compressive strength, the static modulus of elasticity in compression, and the modulus of rupture.

The test results of the compressive and flexural strength tests divide into two distinct groups - those for tests at temperatures above freezing, in which each strength remained approximately constant, and those for tests at temperatures below freezing, in which large increases in each strength were obtained. Maximum increases obtained were 880% for flexural strength and 350% for compressive strength. The percent strength increase was a function of the moisture content of the specimens and was about twice as high for flexural strength as for compressive strength.

The secant and chord moduli of elasticity were found to increase at a decreasing rate for increasing compressive strength.

ACKNOWLEDGEMENTS

Throughout the testing and writing of this investigation, the author received generous assistance from, and the use of the personal libraries of, numerous members of the Department of Civil Engineering. To these members the author is sincerely grateful. Particular thanks are due Professor E.L. Fowler, the author's supervisor, for his guidance and constructive criticism during the preparation of this dissertation and Doctor G. Ford, Head of the Department of Mechanical Engineering, for his advice during the early stages of this investigation.

The author also wishes to express appreciation to the Research Council of Alberta under whose sponsorship this program was inaugurated and to the personnel of the Highway Research Division of the Research Council of Alberta for their technological assistance.

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CHAPTER 1

INTRODUCTION

In the design of concrete structures and pavements, the concrete is assumed to have a specified strength which is independent of the temperature to which the concrete is to be subjected.

The fact that concrete is weaker at high temperatures is well known and is taken into consideration where temperatures in excess of perhaps 250° F are expected. It is also well known that a "frozen" concrete test cylinder will test at a higher strength than a standard cured cylinder; presumably the same result would be obtained from testing a "frozen" concrete beam. However, the magnitude of strength increase to be expected and the reason for this strength increase are not immediately apparent.

This investigation was prompted by the desire to determine the effect of low temperature on the flexural strength of standard cured concrete in order to explain observations on a concrete test road.

1.1 ORIGIN OF PROBLEM

The Alberta Department of Highways constructed a continuously reinforced concrete test road during the fall of 1958 on the Trans-Canada Highway west of Calgary. Observations on the test road were conducted by the Highway Research Division of the Research Council of Alberta and are reported in previous theses, (1,2)*.

In the action of continuously reinforced concrete pavements, cracking is a result of forces caused by shrinkage of the concrete, thermal contraction, wheel loads, and warping due to temperature and moisture differentials. When any of these factors cause a tensile force equal to the tensile strength of the concrete at some section, a crack occurs at that section. Forces are therefore resisted jointly by the concrete and reinforcement at uncracked sections and the reinforcement alone at cracked sections. To prevent wide cracks, it is necessary that the reinforcement not be stressed above its yield point stress. Consequently, continuously reinforced concrete pavements are designed such that subsequent forces cause concrete cracking at some new section rather than stressing of the reinforcement beyond its yield point at previously formed cracks.

However, winter strain gauge observations on the reinforcement at preformed cracks in the test road reported

*Numbers in parenthesis refer to the list of references in the Bibliography.

by Babowal (2) indicated that the reinforcement was being strained beyond the yield point at four out of five crack locations. A report by Wolley (3) on a continuously reinforced pavement in Illinois noted similar observations. Further, in Wolley's report are given the following possible explanations:

i) strain gauge readings as a result of creep of reinforcement were mis-interpreted as strain caused by stress

ii) an increase in tensile strength of concrete at low temperatures prevented cracking and transferred additional force to the reinforcement at previously formed cracks.

Considering i) above, statements by Murphy (4) and Probst and Comrie (5) indicate that no significant creep would occur in the reinforcement at temperatures encountered in pavement slabs. Therefore, the explanation of increased tensile strength appears the more logical. This dissertation will in part attempt to evaluate the possible magnitudes of change in concrete strength at low temperatures.

1.2 PREVIOUS HISTORY

A search of literature yielded only the following references to the effect of low temperature on concrete strength.

A series of tests were performed by Hoff (6) to determine the effect of temperature at time of test on the

strength of cement mortar. Mixes of neat cement and 1:2 and 1:3 mortars were poured as tension briquettes and compression cylinders; in addition, beams of 1:2 mix were poured. Test temperatures included $+34^{\circ}$ F and $+70^{\circ}$ F (standard specimens).

The results of Hoff's work indicated that there was an increase in strength of specimens tested at temperatures below the standard temperature. The percentage increase was independent of the age of the specimens but was to some measure influenced by the percent of cement in the mix. Average values for the different tests were as follows:

i) tension test - neat cement briquettes were about 45% stronger and mortar mixes about 8% stronger at $+34^{\circ}$ F than at $+70^{\circ}$ F,

ii) compression test - cylinder strength of all mixes were about 5% stronger at $+34^{\circ}$ F,

iii) flexural test - beam specimens were about 12% stronger at $+34^{\circ}$ F.

Although Hoff's investigation was of limited volume and included test temperatures above freezing only, it leads to the conclusion that there is a strength gain with decreasing temperature which is somewhat higher for tensile strength than for compressive strength.

Magnel, (7) in his text on prestressed concrete, makes reference to 28 day tests conducted by Huyghe on two normally reinforced and two prestressed beams in which one

of each was tested at +68° F and one at -40° F. Control cubes and beams were poured along with the test beams; results of these tests are shown below.

Again the percentage increase in tensile strength exceeded the percentage increase in compressive strength.

Magnel states; "Both the compressive and tensile strengths of the concrete increase considerably with the fall in temperature; the modulus of elasticity increases also, although not in the same proportions the resistance to both bending and shear increases."

NORMALLY REINFORCED BEAM TESTS

	At +68°F	At -40°F	Increase
Crushing Strength			
20 cm. cubes	4,210 psi	9,230 psi	119%
10 cm. cubes	3,770 psi	6,560 psi	74%
Flexural Strength	526 psi	1,620 psi*	208%
Sonic Modulus	5,260,000 psi	6,480,000 psi	23%

*Error in Magnel's book.

PRESTRESSED BEAM TESTS

	At +68°F	At -40°F	Increase
Crushing Strength			
20 cm. cubes	8,230 psi	11,400 psi	39%
10 cm. cubes	9,270 psi	11,800 psi	27%
** 10 cm. cubes	5,300 psi	8,750 psi	65%
Flexural Strength	735 psi	1,555 psi	111%
Sonic Modulus	5,800,000 psi	6,480,000 psi	12%

** Addition to Magnel's book.

Bauer (8) lists results of compressive tests on concrete cylinders, showing a strength increase of 2% at +45° F and 62% at +10° F over the strength at +70° F. However, it must be noted that each strength was based on one test cylinder only.

Tests reported by Saemann and Washa (9) were somewhat parallel to those of this investigation. Mortar^rs were tested over a temperature range of -70° F to +300° F, evaluating the properties of compressive and tensile strength, modulus of rupture and secant modulus at one-third ultimate stress. Concretes were tested over a range of 0° F to +450° F to evaluate changes in compressive strength and secant modulus. Specimens were cured by 14 days of moist curing, 13 days at +70° F and 50% relative humidity and finally 24 hours conditioning at the test temperature. The properties of the mixes are shown below:

PROPERTIES OF MIXES

Mix	W/C by weight	28 day Cylinder Strength psi	Moisture Content at Test %
a) Mortar			
1M	0.48	5,800	7
2M	0.84	2,500	4
b) Concrete			
1C	0.48	6,000	4
2C	0.84	2,900	4½

Applicable test results are shown in Figs. 1 and 2. They indicate a definite gain in strength for decreasing test temperatures. Higher increases were noted for higher water-cement ratios.

In summary, the fact that concretes and mortars yield higher strengths when cooled and tested at temperatures below the standard has been established. The strength increase is apparently of higher magnitude for test temperatures below freezing. However, the reason for this phenomena and the strength increase to be expected from concrete specimens cured in the standard manner and tested at low temperatures, has not been determined.

FIG. 1.

FIGURE 1.
TEST TEMPERATURE V.S. PERCENT INCREASE
IN MORTAR PROPERTIES
RESULTS OF TESTS BY SAEMANN AND WASHA (9)

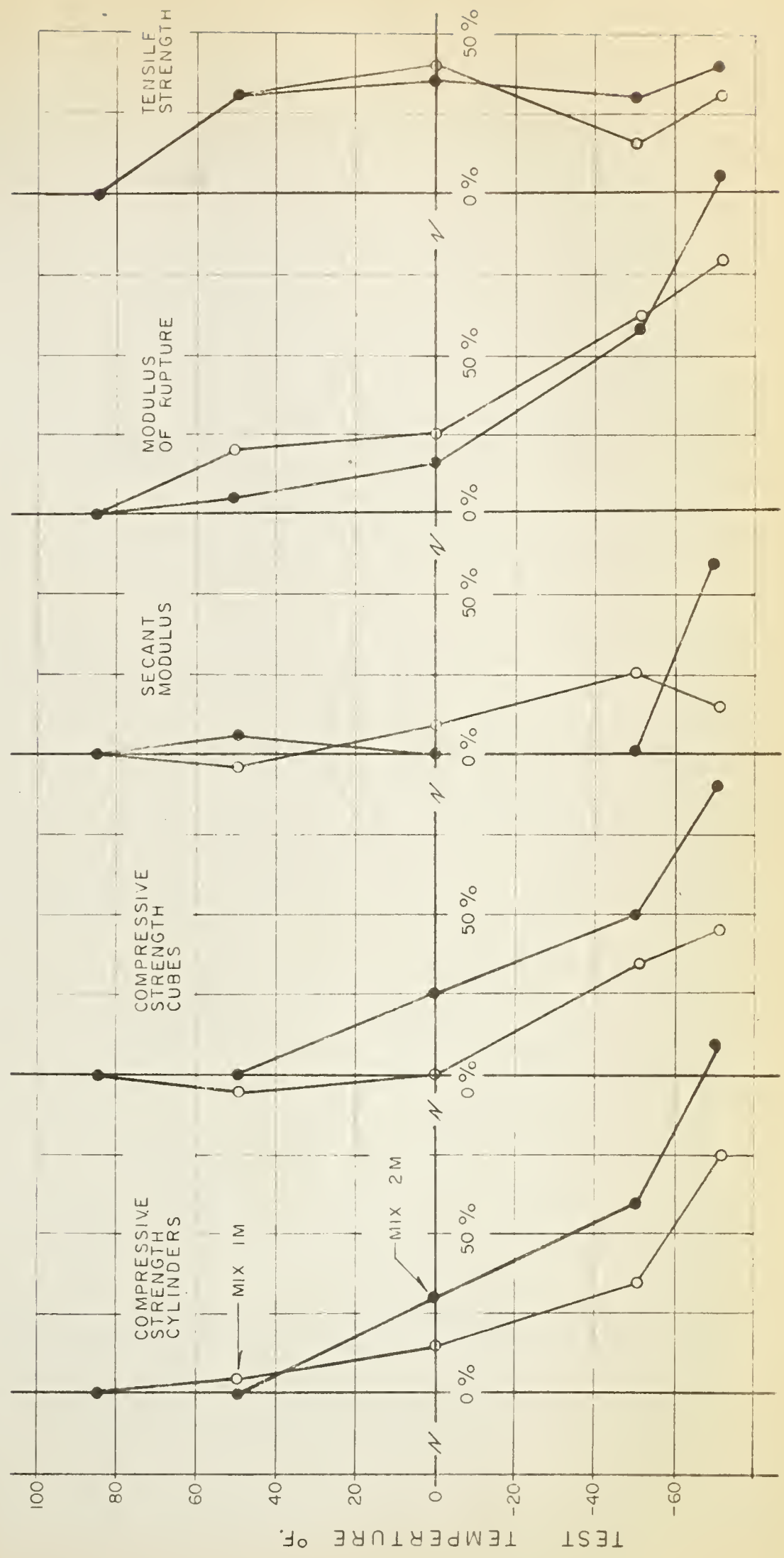
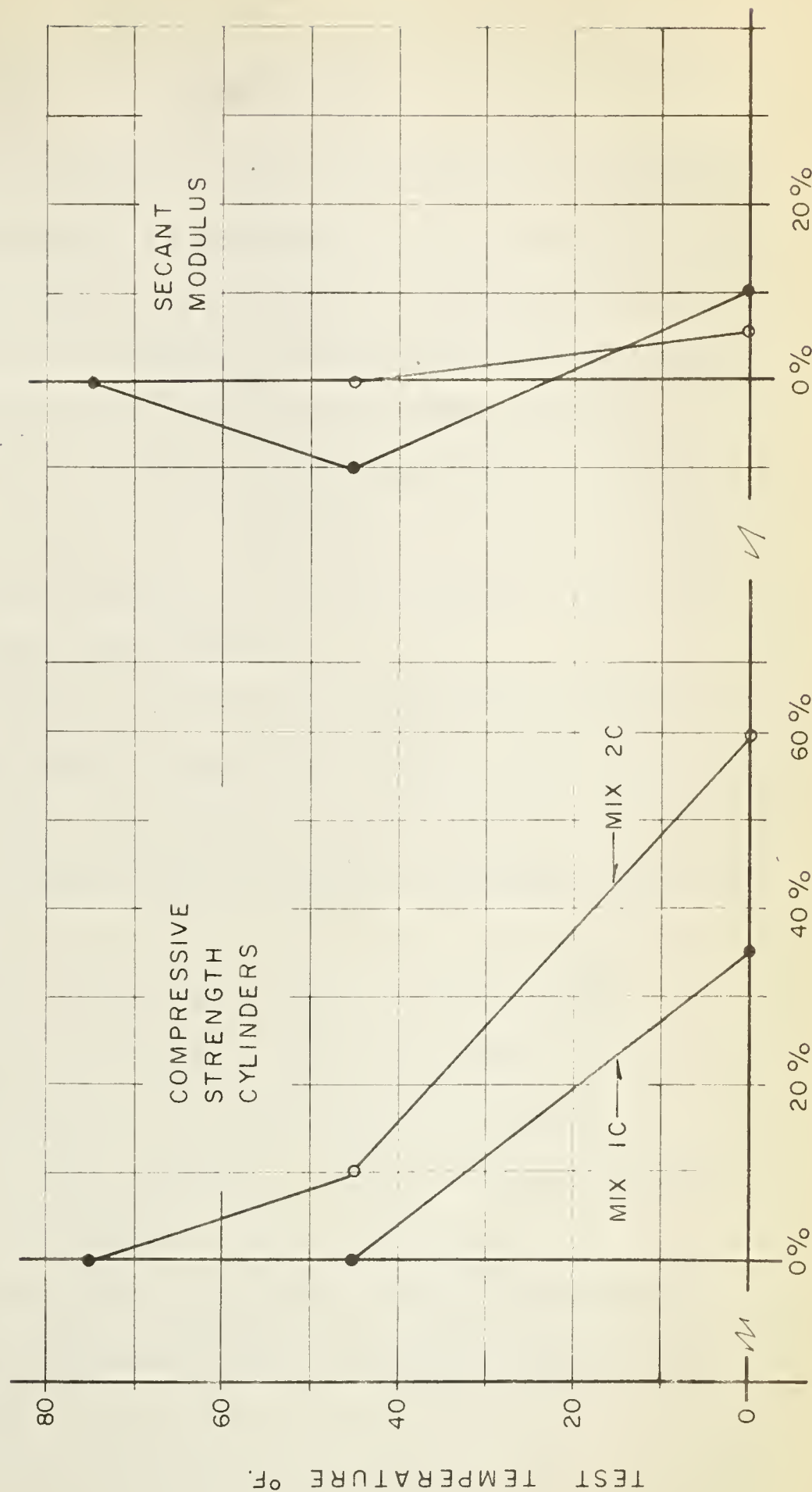


FIGURE 2.

TEST TEMPERATURE V.S. PERCENT INCREASE IN CONCRETE PROPERTIES

RESULTS OF TESTS BY SAEMANN AND WASHA (9)



CHAPTER 2

SCOPE OF INVESTIGATION

It was the purpose of this investigation to determine the effect of low temperatures on the compressive and flexural strength and on the modulus of elasticity of concrete. Magnitudes of change in strength and elastic properties were determined by comparing the test results of specimens tested at low temperatures with those of specimens tested at the standard temperature. It must be emphasized that this investigation was not concerned with the effect of low curing temperatures.

Test specimens consisted of three inch diameter by six inch cylinders and three inch by three inch by eighteen inch beams. All specimens were molded and cured in the standard manner. The following parameters were considered:

1. a temperature range from -30°F to $+70^{\circ}\text{F}$,
2. three mix designs, 2,000 psi, 3,000 psi and 4,000 psi 28 day design strengths,
3. four curing times - 7 days, 28 days, 2 months and 4 months.

In addition to the above, a special set of tests was used to determine the effect of reduced moisture content on the strength changes.

The initial testing program included four temperature intervals; -30°F , 0°F , $+30^{\circ}\text{F}$, $+70^{\circ}\text{F}$. Results of 7 day tests indicated an increase in strength at the lower temperatures much in excess of that anticipated. Consequently, the testing program was expanded in an attempt to fill the gaps in test results; test temperatures of -15°F , $+15^{\circ}\text{F}$, and $+50^{\circ}\text{F}$ were added. In addition, the previous $+30^{\circ}\text{F}$ testing was shifted to $+35^{\circ}\text{F}$ so that the expanded program consisted of three test temperatures below the freezing point of water and three above. The $+70^{\circ}\text{F}$ test results were of course the standards to which comparisons were made.

To ascertain the quality of the various batches, cubes were cut from broken portions of the beams and tested in compression. Also, for the new batches of the expanded program (-15°F , $+15^{\circ}\text{F}$, $+50^{\circ}\text{F}$), additional control cylinders were molded. These control cylinders were tested at the standard temperature as companion cylinders to their low-temperature-test counterparts.

In total, the program consisted of tests on approximately 650 cylinders and 300 beams. Two tests were made on each beam. In view of the large volume of data obtained, an attempt was made to analyze the results using statistical methods.

CHAPTER 3

RELATED ASPECTS OF CONCRETE TECHNOLOGY

Following are literature summaries concerning various aspects of concrete technology related to this investigation. Reference will be made to these summaries in subsequent chapters.

3.1. STRUCTURE AND MOISTURE CONDITIONS IN CONCRETE

Concrete basically consists of "active" paste and "inert" mineral aggregate. The paste consists of the products of the hydration of the cement and water, principally calcium silicate gel and crystalline particles. As hydration proceeds, the volume of the gel surrounding a cement grain is increased as more water is combined with the cement and the existing gel is stiffened and strengthened (see Troxell and Davis (10) p.24.) The rate of hydration depends mainly on the temperature and moisture conditions of curing and the chemical composition and fineness of the cement. In hardened cement paste the hydration process becomes asymptotic with time.

As defined by Powers (11), in order of decreasing magnitude of the size of the components, the structure of hardened paste consists of air pores, capillary cavities, gel particles, and gel pores.

- i) Air pores are voids left by the evaporation of uncombined water.

- ii) Capillary cavities or channels occur as air or water filled voids in the paste between the air pores.
- iii) Gel particles are sub-microscopic crystals of the order of 85 to 100 Angstrom units in average diameter. The linking of the particles at points of contact form the collodial gel.
- iv) Gel pores are the spaces between points of contact of gel particles.

The relative percent of the total volume occupied by the above components varies as the water-cement ratio, the curing period and conditions of curing, and the richness of the mix. For example, the gel particles would occupy their largest percentage of the total volume for the conditions of a rich mix of low water-cement ratio cured for a long period under ideal curing conditions.

Both Lynam (12) and Menzel (13) indicated that moisture exists in hardened cement paste in three forms;

- i) Chemically combined water - this water is inert with respect to the action of the paste.
- ii) Collodial water held on the surface of the gel particles (in gel pores); the action of this water is greatly affected by the surface tension in the sub-microscopic pores.
- iii) Free or mechanically held water in capillary cavities.

Powers points out that the water in ii) and iii) fore-mentioned is actually a solution. In addition, depending on environmental conditions, moisture may exist in the air pores, particularly at early ages.

3.2. MECHANISM OF FREEZING IN CEMENT PASTE

The following is a summary of Powers' (11) theory of the freezing action in concrete. It must be pointed out that Powers considered only saturated samples of hardened cement paste; these samples would show maximum effects.

The freezing mechanism may be explained in terms of two processes, the second dependent on the first.

- i) The free water freezes in the capillary cavities, resulting in hydraulic pressure.
- ii) Ice bodies grow in the capillary cavities (or air pores) by the diffusion of water from the gel.

The basis for this theory is the assumption that the formation of ice is restricted to the capillary cavities, that is, such cavities are the only places where ice may exist in the paste between the air pores. Due to the smallness of the cavities, only limited freezing will take place at the normal freezing point. Pressure due to surface tension lowers the freezing point of much of the water so that significant freezing does not take place until the temperature is below the normal freezing point. Gel pores are of course much smaller than capillary cavities and consequently no

freezing will take place in them (at least not at temperatures above -78°C).

Consider an air pore surrounded by paste being subjected to decreasing temperatures. Assuming the paste is saturated, the capillary cavities around the pore are filled with water. As the temperature reaches the freezing point, a small amount of ice forms, presumably in the largest cavity. Since the ice occupies a greater volume than that of the water from which it is formed, hydraulic pressure is produced in the remaining unfrozen water. This pressure can only be relieved by expansion of the cavity or by escape of unfrozen water through channels towards the air pores. This action is illustrated by Fig.3a which shows a relatively porous sample being subjected to decreasing temperatures. The instant freezing begins, there is a rapid expansion of the paste, caused by hydraulic pressure.

As the remainder of the water in a cavity becomes frozen, a difference in energy results between the ice surface and the water in the gel pores. The water acquires an energy potential enabling it to move into the cavity and cause the ice crystal to grow, enlarging the cavity. The process is called surface diffusion; it is illustrated in Fig.3b. Here a relatively dense specimen did not commence expansion until the temperature was -19°C . Additional lowering of temperature resulted in expansion due to hydraulic pressure. The temperature was held constant at -21°C ;

FIGURE 3.

FREEZING ACTION IN CONCRETE PASTE

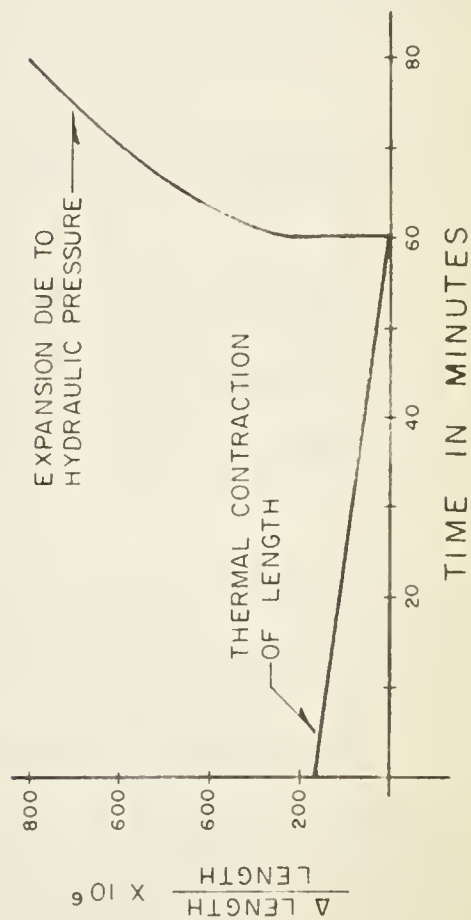
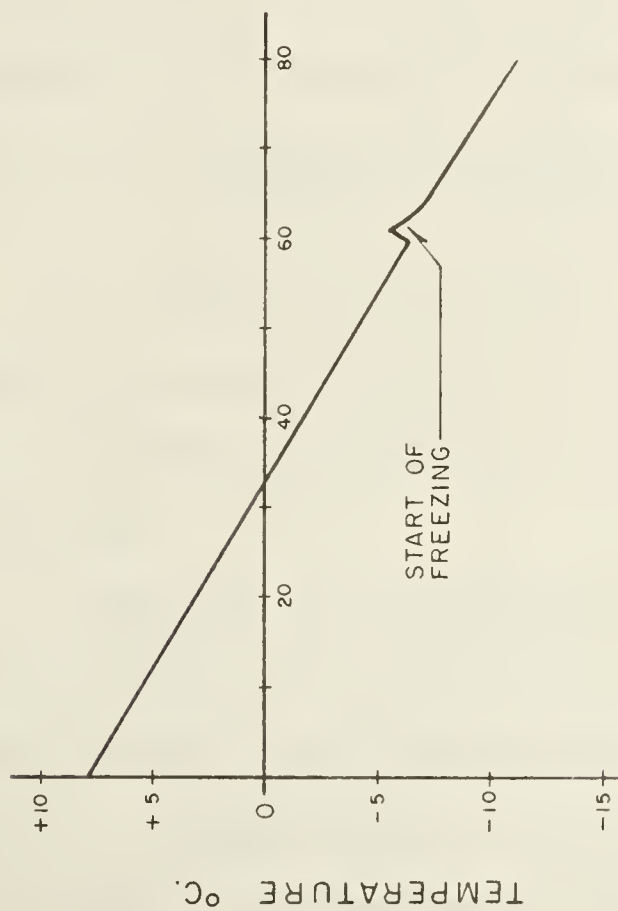


FIG. 3a. - EFFECT OF HYDRAULIC PRESSURE

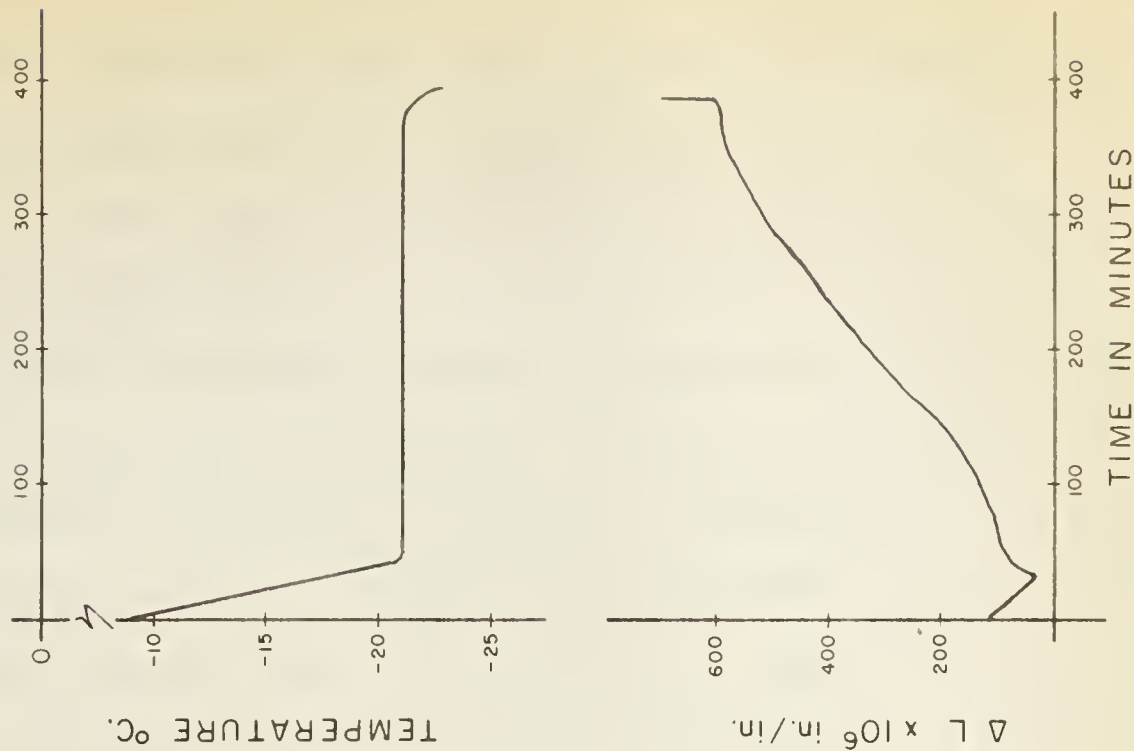


FIG. 3b - DIFFUSION ACTION

PRESSURE

expansion throughout this period was due to diffusion of the gel water into ice in the capillary cavities.

Since the diffusion process is relatively slow, extensive expansion due to hydraulic pressure can take place with a negligible amount of expansion from diffusion as for the specimen of Fig.3a. It therefore appears that development of hydraulic pressure is dependent on the rate of freezing, and the growth of ice bodies by diffusion is dependent on the length of time at low temperature.

The above discussion has been limited to considerations of the diffusion of gel water to the capillary cavities. The same action would take place between the ice on the surface of air voids and adjacent gel water. This action is of secondary importance.

3.3. EFFECT OF LOW TEMPERATURES ON CURING

The effect of low curing temperature on the strength of concrete has been established by such researchers as Timms and Withey (14) and more recently by Klieger (15).

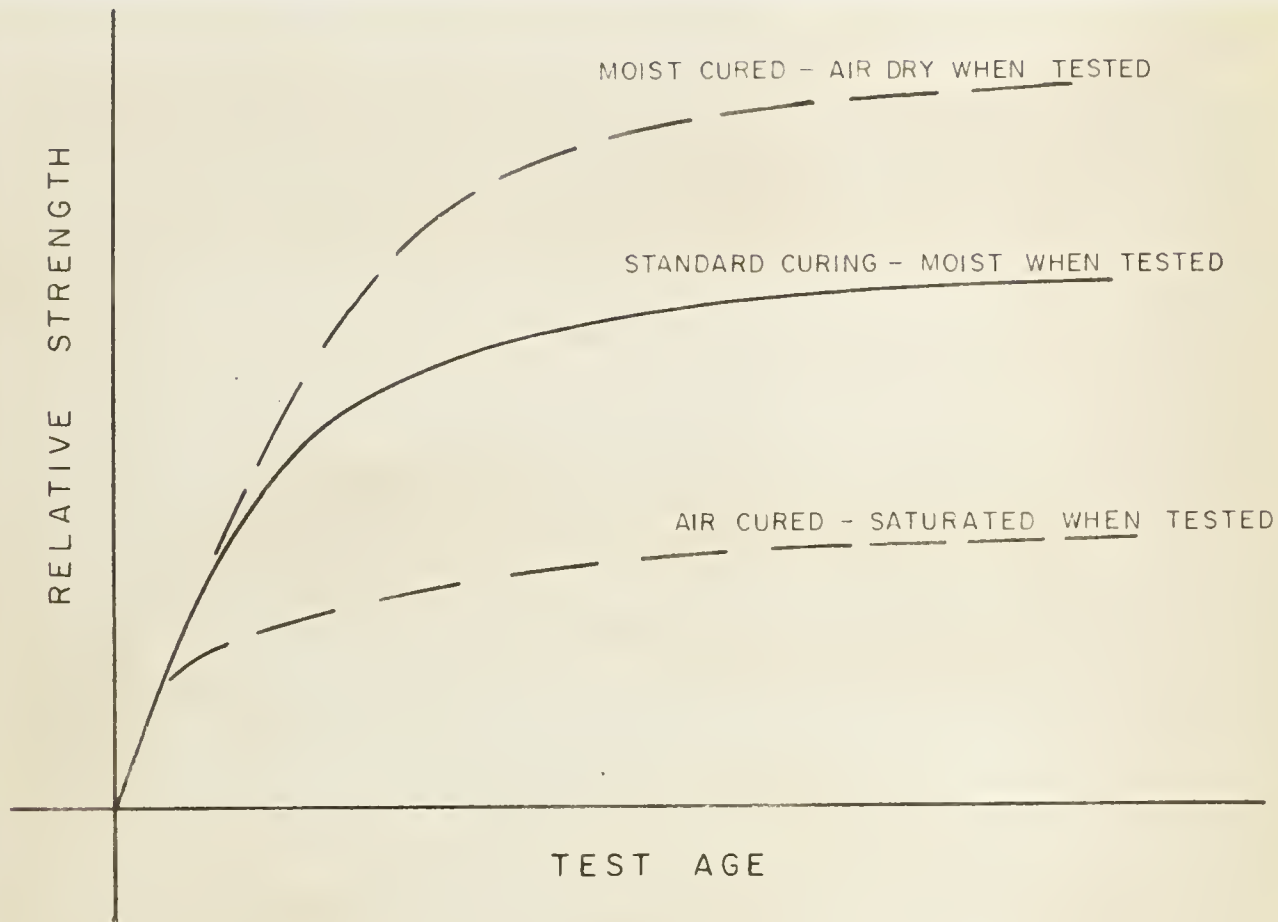
Basically low temperatures slow down the rate of gain of strength (i.e. slow down hydration). The effect is apparently the same for compression and flexural strengths. Strength gain is virtually stopped for specimens subjected to temperatures below about +10°F. (See Plowman (16)).

There is general agreement on the forementioned effect but disagreement on a numerical value of the critical age of freezing. (i.e. the age after which freezing can take place without the specimen suffering permanent damage and consequent loss of strength). Wiley (17) claims the critical age is that at which the cement paste has developed sufficient strength and adhesion to the aggregate such that free water cannot collect around the rock particles and, in freezing, break the bond. Klieger subjected specimens to $+25^{\circ}\text{F}$ after 24 hours standard moist curing with no detrimental effects; however, Wiley's tests indicate a minimum critical age of 7 days for specimens frozen to $+5^{\circ}\text{F}$ and Timms' and Withey's tests show some detrimental effect for specimens subjected to $+16^{\circ}\text{F}$ after 3 days standard curing.

3.4. EFFECT OF MOISTURE CONTENT ON STRENGTH

3.4.1. COMPRESSION TESTS

The classical paper on this subject is one by Gilkey (18), the findings of which are presented in part below.



EFFECT OF MOISTURE CONTENT
ON CONCRETE STRENGTH

The upper envelope defines the strength of specimens moist cured until shortly before testing, at which time they are air dried. The lower envelope defines the strength of specimens cured by exposure to air at room temperature and then saturated by immersion in water prior to testing. Gilkey claims the strength gains or losses are due to the drying or saturation only and are therefore independent of curing effects.

Troxell and Davis (10) in a discussion of Gilkey's work indicate that a compression specimen will exhibit 20 to 40 percent more strength when air dry than when saturated. They attribute this to;

- "1) the greater density of dry (and therefore contracted) paste.
- 2) initial tensile stresses in the paste due to localized restraint of paste shrinkage by pieces of aggregate.
- 3) possible development of hydrostatic pressure in saturated paste."

In addition, they point out that the changes in strength are probably attributable to changes in the gel structure in that increased availability of moisture produces swelling and weakening of the gel and drying produces shrinkage and strengthening of the gel.

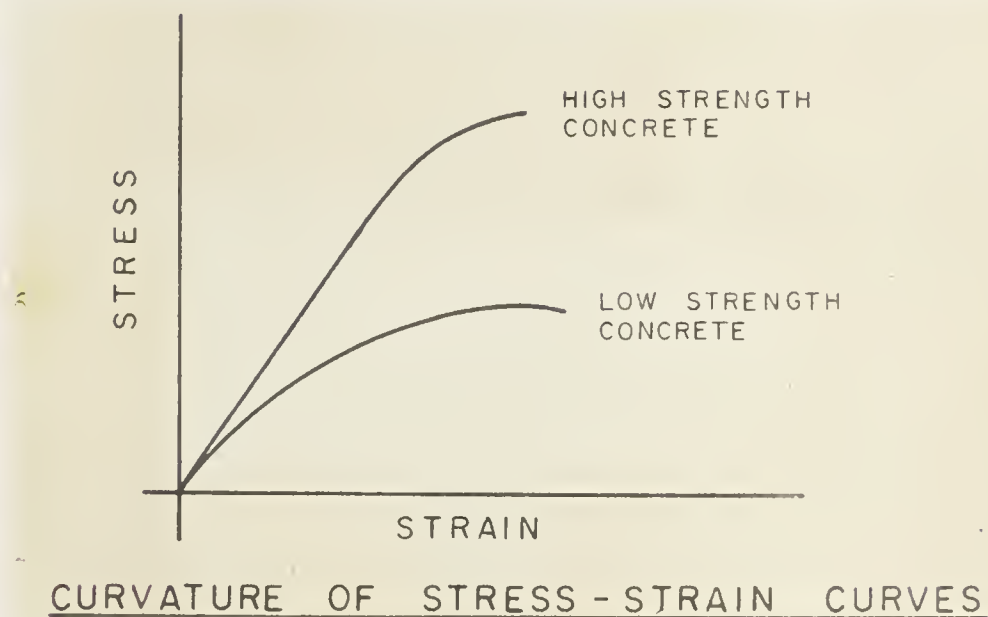
3.4.2. FLEXURAL TESTS

Walker and Bloem (19) in a review of previous work on this subject summarize by saying that flexural strength showed great sensitivity to changes in moisture content; partial drying apparently would reduce strength and thorough drying increase it. They conducted tests to substantiate this; results show that drying causes substantial strength reduction at early ages and strength increases at later ages. The following explanation is offered: at early ages differ-

ential shrinkage by drying caused tensile stresses in the outer fibres which reduced the load carrying capacity; at later ages this effect was reduced due to the advanced state of hydration and was overshadowed by the strength gain due to drying.

3.5 MODULUS OF ELASTICITY OF CONCRETE

The stress-strain diagram for concrete is a curve, the amount of curvature depending mainly on the ultimate strength as shown below.



The above shapes were substantiated in reports by Walker (20) and Thoman and Raeder (21). Walker gave the general equation of the curve as

$$f_c = k (e_c)^n$$

where f_c = the unit stress in the concrete

e_c = the unit deformation in the concrete

k = a constant

n = exponent

If the definition of modulus of elasticity is taken as the ratio of stress to elastic strain, then application of this term to concrete is erroneous in that measurement of strain in static* concrete tests includes plastic as well as elastic deformations. Walker has defined the modulus of elasticity of concrete as the ratio of an increment of stress to a corresponding increment of strain.

Because concrete is an imperfectly elastic material, different methods of measuring the modulus of elasticity have been devised including the tangent and initial tangent moduli, the secant modulus and the chord modulus. A graphical comparison is shown overleaf.

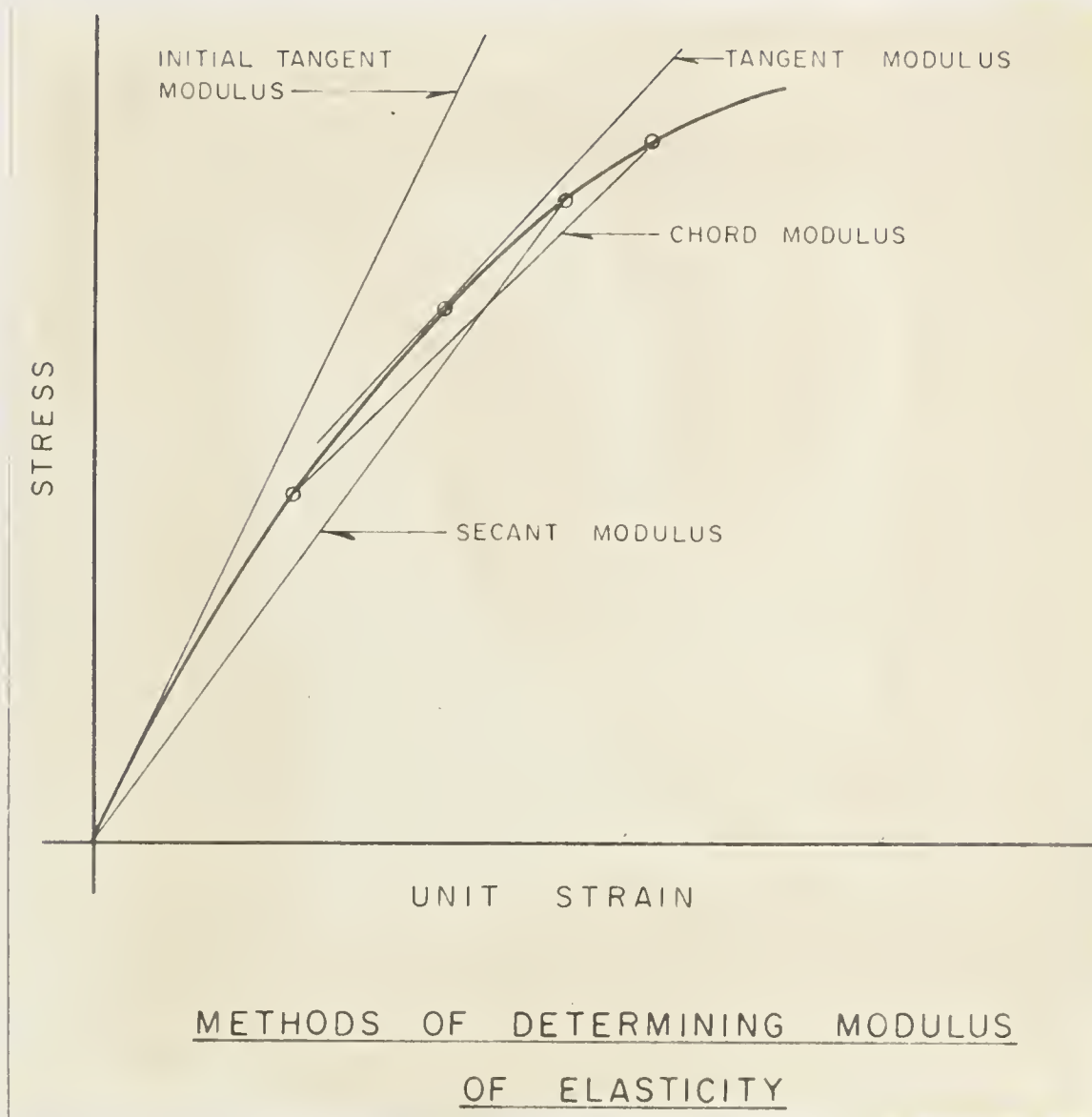
Values of the initial tangent and secant moduli are most commonly used; the chord and secant moduli have the advantage that no estimation is required.

The factors which influence the strength of concrete generally influence the modulus of elasticity in a similar fashion although usually to a lesser degree. Two of the more significant factors are the properties of the aggregate and the age of the concrete.

Load applied to a concrete specimen is resisted by the paste and aggregate. It would be expected that

*Throughout this dissertation only the static (as differentiated from the sonic) modulus of elasticity will be considered.

aggregate with higher moduli of elasticity would increase the overall modulus of elasticity of the specimen. This was substantiated by Thoman and Raeder. Walker demonstrated that the modulus also increases as the size of the coarse aggregate and fineness modulus are increased.



Numerous investigators (see Troxell and Davis (22)) have stated that the modulus of elasticity of concrete increases with age at a steadily decreasing rate. This statement should be clarified by saying that age affects the

modulus of elasticity only insofar as it affects the strength as indicated in tests by Walker and Freudenthal and Roll (23).

It is desirable to express the modulus of elasticity in terms of the compressive strength. A standard expression is difficult due to the effect of variables and the fact that no standard definition of, or test for, the modulus of elasticity has been defined. It is generally agreed that the modulus of elasticity is higher for higher strength concretes. Troxell and Davis state that there appears to be no general direct relationship. However, extensive tests by Walker indicate that an expression of the form

$$E = k f'_c{}^m$$

where E = modulus of elasticity of concrete
 k = constant
 f'_c = 28 day compressive strength of concrete
 m = exponent

would give reliable results. For design purposes, linear relationships are generally used as approximations for the limited range of compressive strengths considered. Some of these are:

i) N.B.C. equation

$$E = 1,000 f'_c$$

ii) A.C.I. - A.S.C.E. Joint Committee 323 equation

$$E = 1,800,000 + 500 f'_c$$

Linear relationships give values of the modulus of elasticity too high for both low or high compressive strengths. Jensen (39) proposed a non-linear form of the relationship between the initial tangent modulus of elasticity and the compressive strength:

$$E = \frac{6 \times 10^6}{1 + \frac{2,000}{f'_c}}$$

3.6. MODULUS OF RUPTURE

The modulus of rupture as defined by A.S.T.M. Standard C78 is used as a measure of the flexural strength of concrete. In computing its value the following assumptions are made:

- i) plane sections remain plane during bending.
- ii) Hooke's Law is applicable to concrete, i.e., stress is linearly proportional to strain.

The validity of the first assumption has been verified by numerous authors such as Hognestad (24) and it must be considered a good approximation. However, the second assumption is not true in that it does not account for the plastic action of concrete at high stresses. If it is assumed that the stress-strain diagram for concrete in tension is similar to that for compression up to some value of ultimate tensile

strain as indicated by Johnson (25), then it will have a shape as shown in Fig. 4A. Therefore, the stress distribution in a plain concrete flexural specimen immediately before failure will be as shown in Fig. 4B. The stress distribution of Fig. 4B illustrates why values obtained for modulus of rupture are always greater than those of tensile strength for specimens poured from the same concrete. A.S.T.M. Standard C78 presents a formula for determining modulus of rupture of beams loaded at one-third points with failure in the middle third section,

$$f_r = \frac{PL}{bd^2}$$

which is derived directly from the familiar expression

$$f = \frac{Mc}{I}$$

Since the compressive strength of concrete is its basic strength property, it is desirable to express the modulus of rupture as a function of this strength. Extensive research has been done on this problem; however, consistency of results is poor.

Until recently, values of the modulus of rupture were given in the form

$$f_r = k f'_c$$

where f'_c is the 28 day compressive strength.

The particular value of the constant, k , selected was

FIG. 4

FIGURE 4.

STRESS - STRAIN RELATIONSHIPS
FOR PLAIN CONCRETE IN FLEXURE

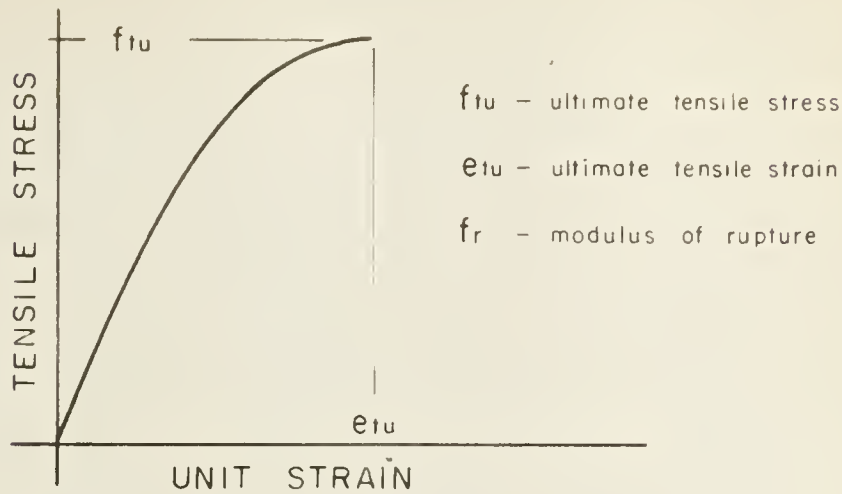


FIG. 4A. - STRESS - STRAIN RELATIONSHIP
FOR CONCRETE IN TENSION

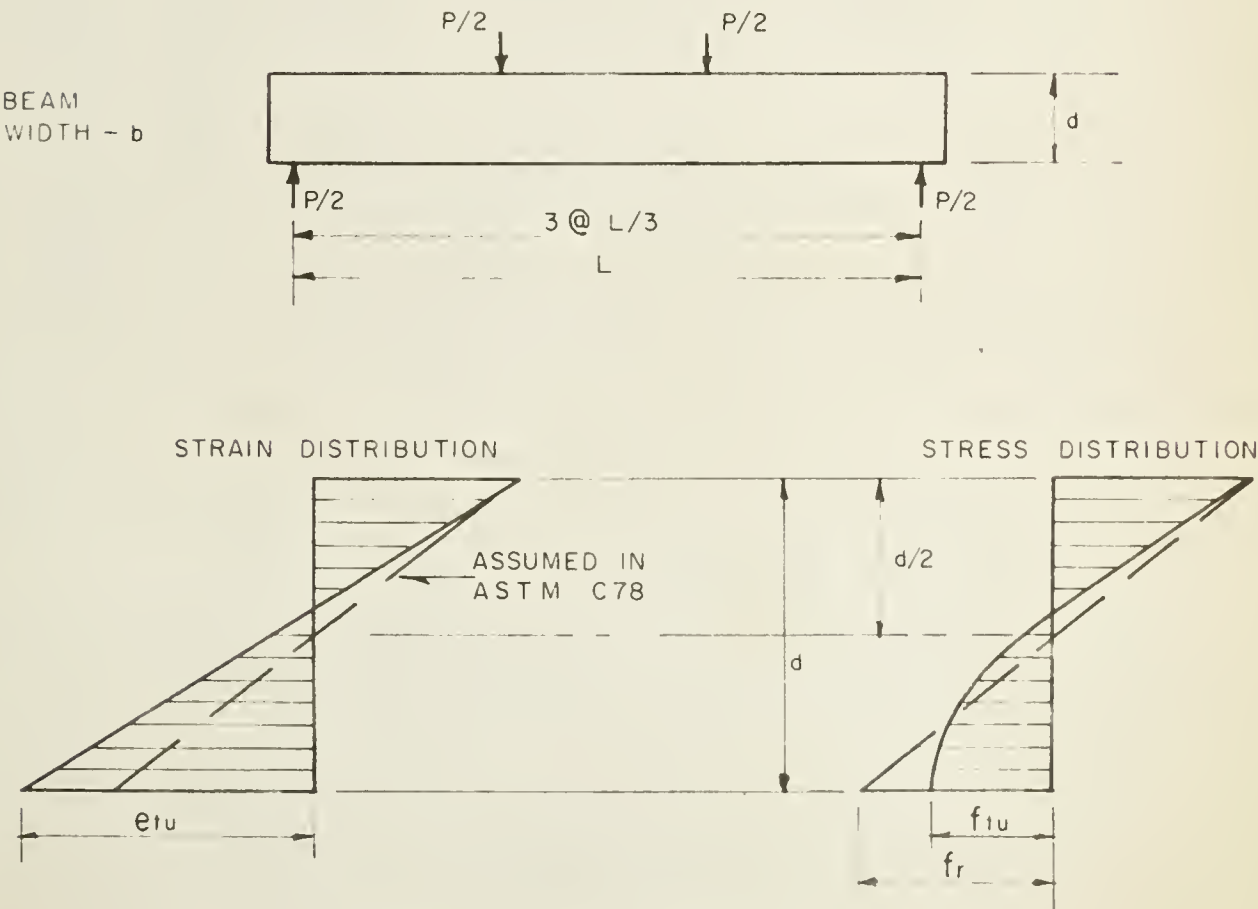


FIG. 4B. - STRESS AND STRAIN DISTRIBUTION
AT FAILURE

FIGURE 5

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH
AND MODULUS OF RUPTURE

RESULTS OF TESTS BY GONNERMAN
AND SHUMAN (29)

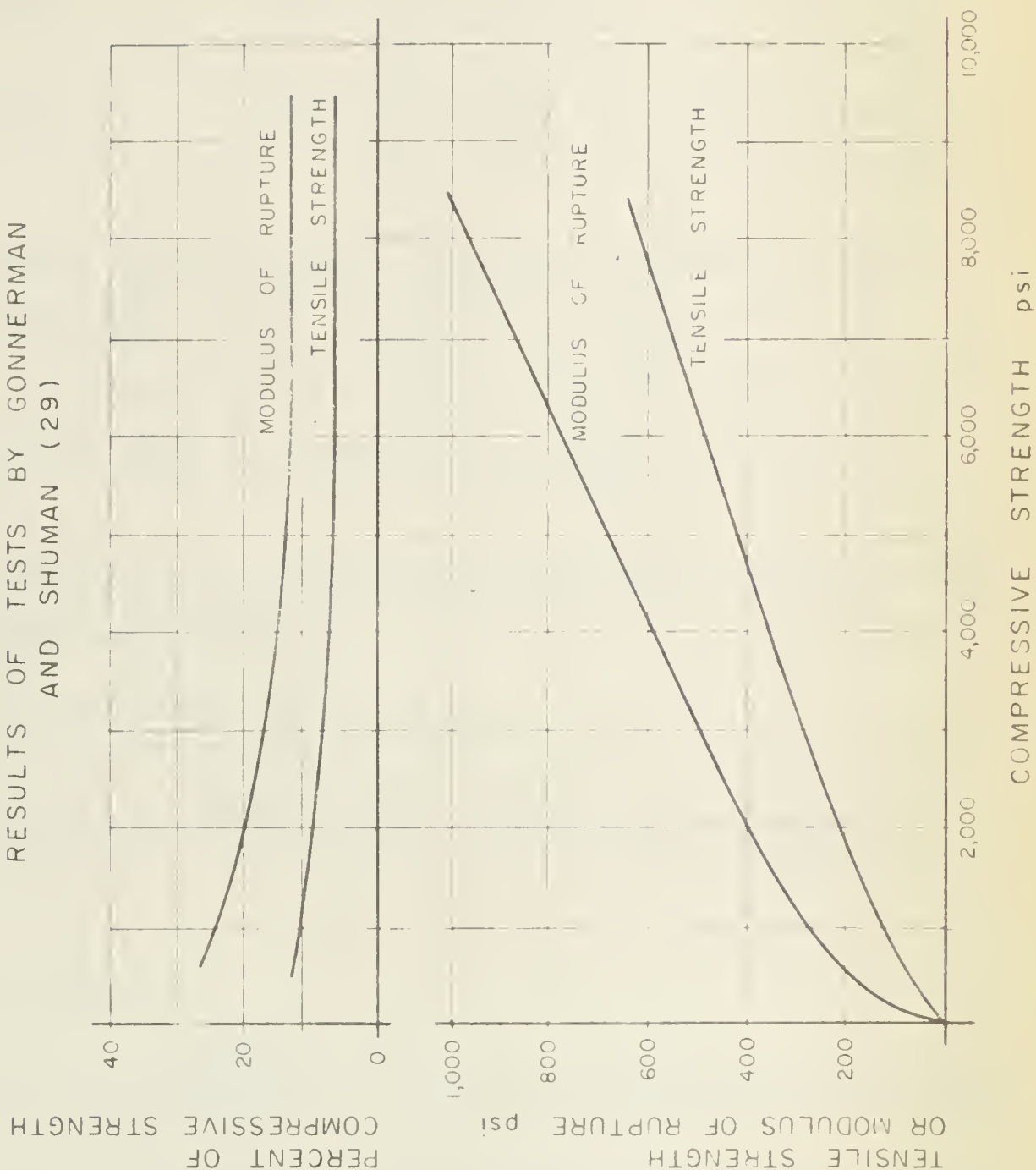


FIG 5

applicable to a limited range of f'_c . A resume of some results are shown below.

- i) Johnson (25) $f_r = (0.29 \text{ to } 0.14) f'_c$
- ii) Walker and Bloem (26) $f_r = 0.14 f'_c$ for f'_c between 3,500 psi and 6,500 psi
- iii) Abrams (27) $f_r = 0.26 f'_c$ at $f'_c = 1,000$ psi
 $f_r = 0.15 f'_c$ at $f'_c = 4,000$ psi
- iv) Kesler (28) $f_r = 0.22 f'_c$ for $f'_c = 2,000$ psi
 $f_r = 0.12 f'_c$ for $f'_c = 7,500$ psi

Investigators agree that the modulus of rupture is a much higher percentage of the compressive strength for lower values of the compressive strength. This is best illustrated by results of tests by Gonnerman and Shuman (29) shown in Fig.5.

More recent investigations give the relationship in a non-linear form such as:

i) Morrow and Viest (30) $f_r = 9.5 \sqrt{f'_c}$
 (from Kesler's data)

The A.C.I. - A.S.C.E. Joint Committee #323 has adopted a conservative value of this expression in their Recommendations for Prestressed Concrete as follows:

$$f_r = 7.5 \sqrt{f'_c}$$

ii) Zwoyer (31)

a) $f_r = \frac{3,000}{2 + \frac{12,000}{f'_c}}$ for $1\frac{1}{2}$ " maximum size aggregate

b) $f_r = \frac{3,000}{4 + \frac{12,000}{f'_c}}$ for $3/8$ " maximum size aggregate

The difficulties in obtaining uniform results are discussed in succeeding paragraphs.

Gonnerman and Shuman reported extensive results definitely indicating that the modulus of rupture increased for increases in fineness modulus and increases in the maximum size of aggregate. These results are substantiated by work by Zwoyer shown above. On the contrary, Kellerman's (32) results show that decreasing the maximum size of aggregate increases the modulus of rupture; Kaplan (33) agrees with these findings.

Whether the presence of coarse aggregate increases or decreases the modulus of rupture apparently depends on the surface characteristics of the aggregate and the aggregate's ability to develop bond. Examinations of the forementioned reports shows that rough textured or angular aggregates increase the modulus of rupture while smooth aggregates decrease it. The large variations possible in values of the modulus of rupture by merely changing the coarse aggregate in a mix are well illustrated by Walker and Bloem (26).

All authors agree that better uniformity of test results come from smaller ratios of maximum size of aggregate to beam depth.

The effect of varying beam depths on the modulus of rupture was investigated by Kellerman, Walker and Bloem and A.A.S.H.O. (34). All concluded that the modulus

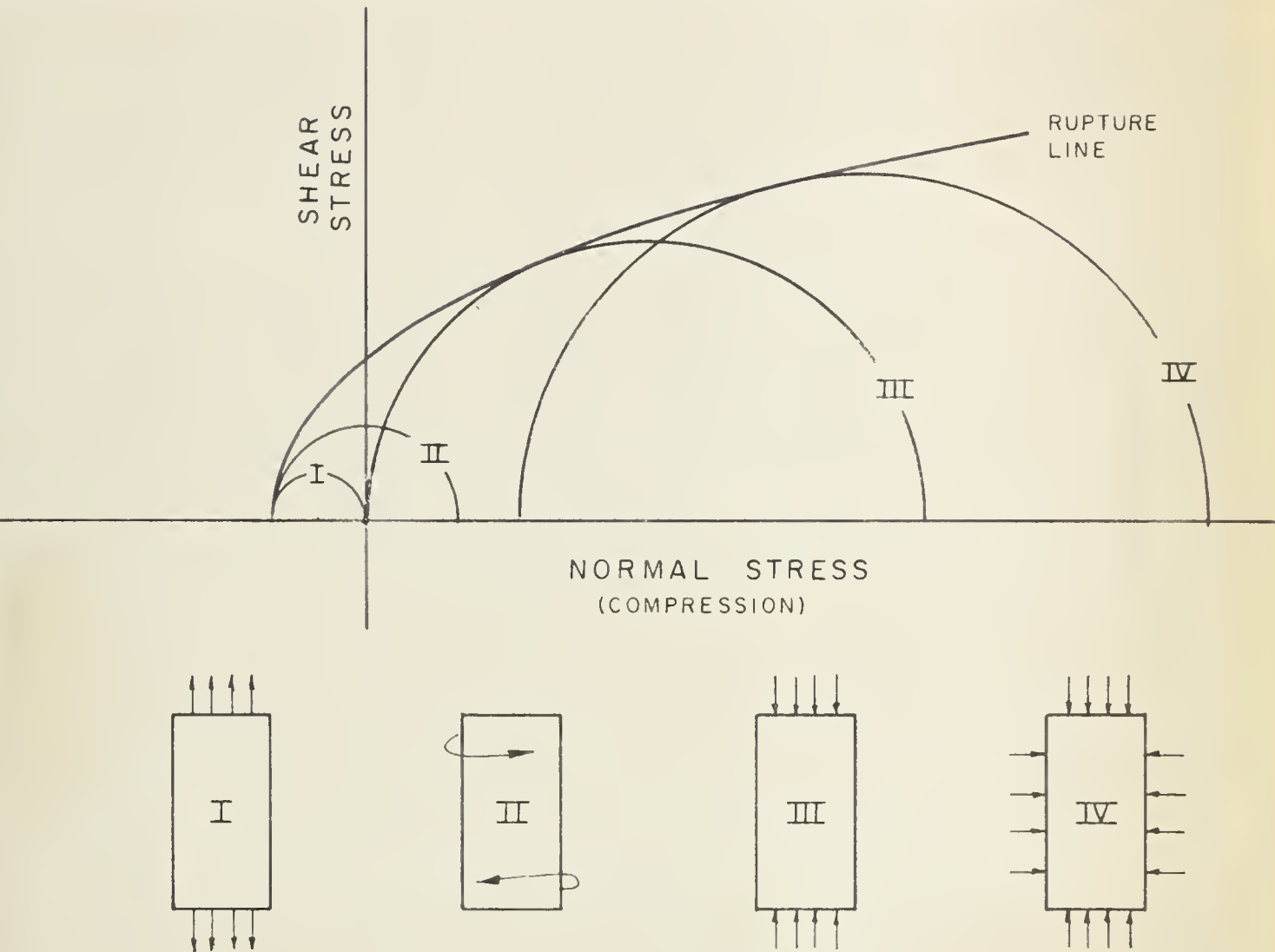
decreased in direct proportion to increase in depth. Increases of about 10% were noted for 4 inch beam depths as compared with 10 inch depths.

The effect of the concrete age on the flexural strength was investigated by Gonnerman and Shuman. Their results indicate that the curve depicting the age - modulus of rupture relationship was of similar shape to the age - compressive strength relationship except that the modulus increased at a more rapid rate with respect to age. Similar observations were reported by Otto (35) whose results show the 7 day modulus to be 79% of the 28 day compressive strength as compared with 67% as the corresponding figure for the 7 day compressive strength.

3.7. THEORETICAL FAILURES

3.7.1. CYLINDERS IN COMPRESSION

The stress conditions on cylinder failure planes for various forms of loading may be illustrated by the Mohr Rupture Theory as noted by Kesler and Siess (36) and shown below.*

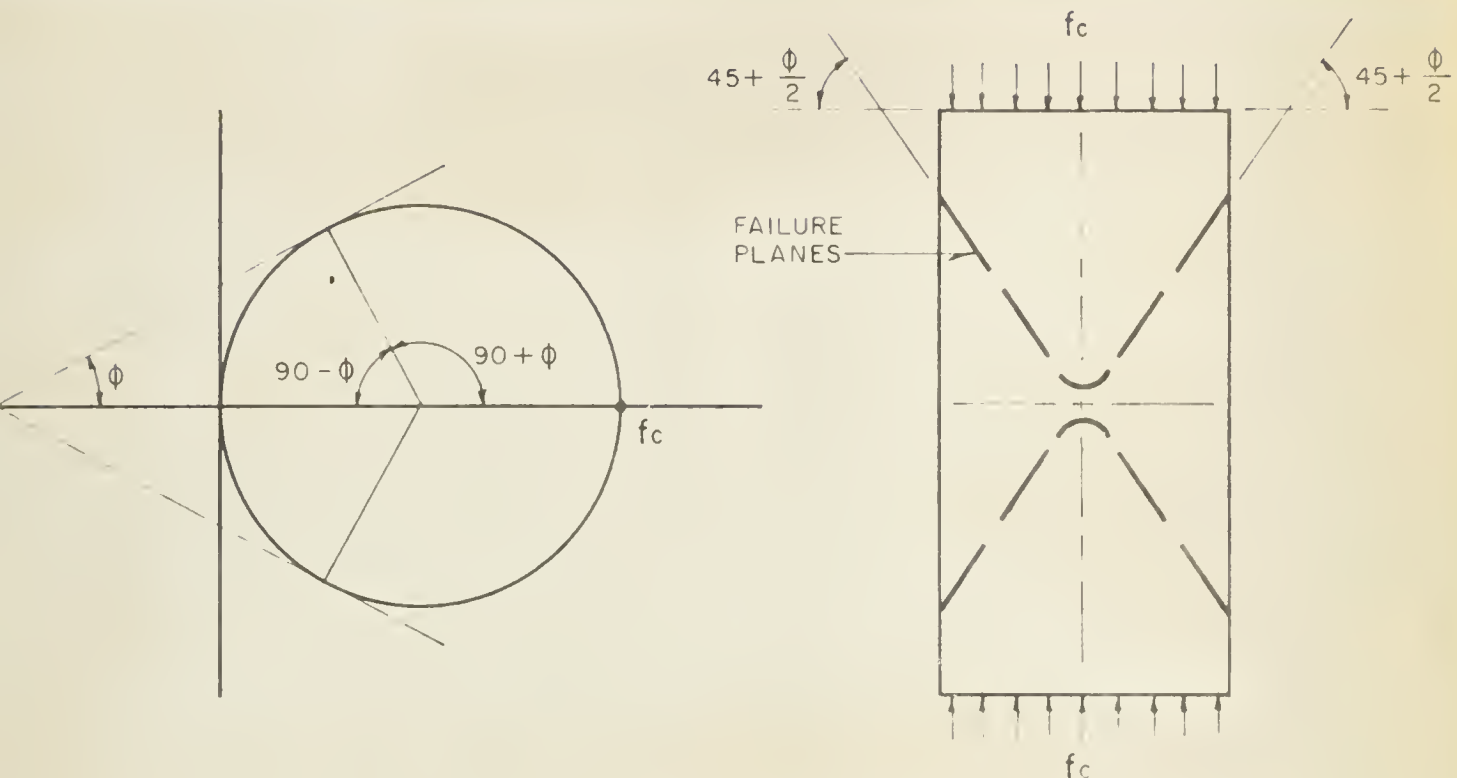


MOHR'S RUPTURE THEORY FOR VARIOUS
LOADING CONDITIONS

*Figures shown to left of the ordinate axis have not been substantiated experimentally.

By the Rupture Theory, failure occurs when the stress conditions are such that a circle becomes tangent to the Rupture Line.

For a cylinder loaded in the standard manner (III preceding page) the angle that the theoretical failure plane makes with the cross-section at right angles to the direction of loading may be determined as follows:



CYLINDER FAILURE UNDER STANDARD LOADING

where - f_c is the ultimate strength of the cylinder in axial compression

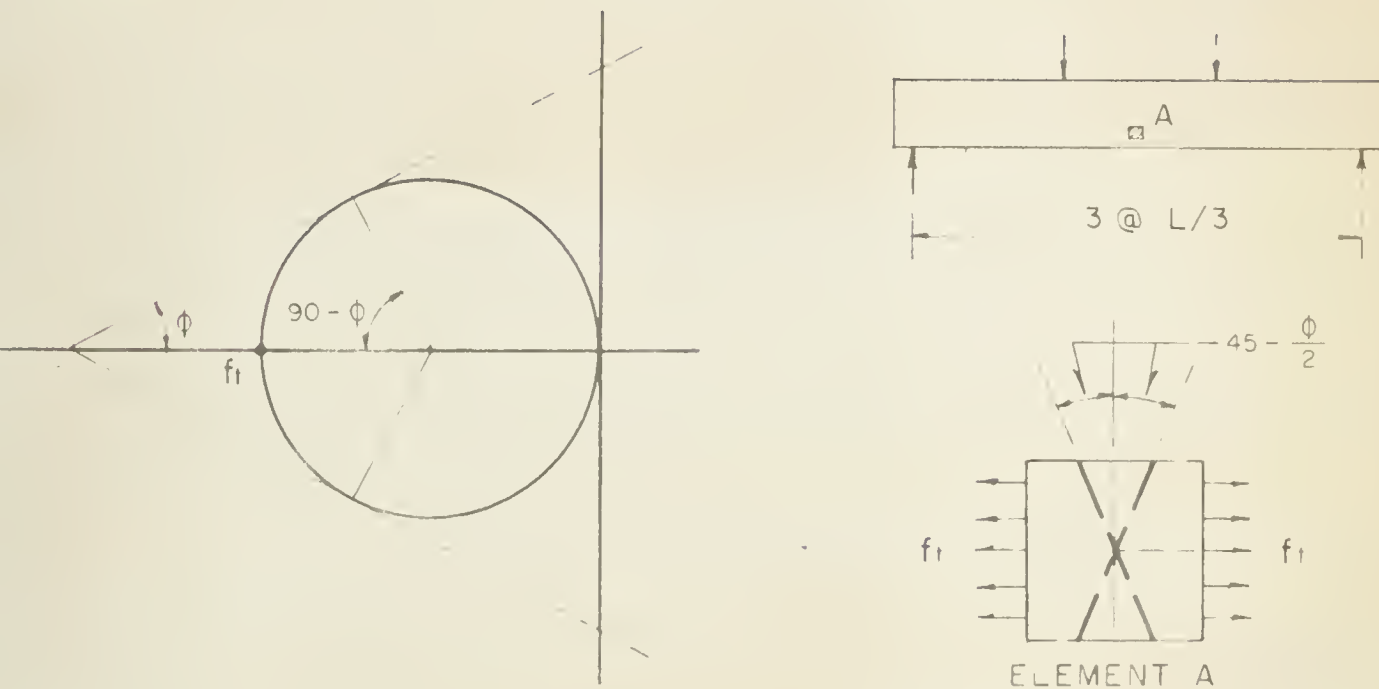
ϕ is the angle of internal friction of the concrete

Troxell and Davis (10) state that ϕ is approximately equal to 20° ; therefore, the failure angle would be about 55° to the right cross-section. This value may be altered by end effects.

3.7.2. BEAMS IN FLEXURE

Under normal conditions, failure in a beam test would be expected to consist of tensile failure of the mortar and bond failure around the pieces of aggregate. Aggregate of normal strength would not be broken.

The direction of the failure plane will depend on the magnitude of shear stress at the critical section. The case for one-third point loading assuming negligible shear at the critical section is shown below.



BEAM FAILURE UNDER ONE-THIRD POINT LOADING

For this case it is apparent that the failure plane will be approximately parallel to the direction of loading.

CHAPTER 4

TEST SPECIMENS

This chapter is concerned with the manufacture of the test specimens. Included are the physical properties of the mix constituents and descriptions of the mixing and molding operations.

4.1. MATERIALS

4.1.1. AGGREGATES

Aggregates were selected from the stockpiles of a local supplier, and transported in bags to minimize segregation. The source of the aggregate was the Edmonton Beach pits. Both the coarse aggregate and fine aggregate were observed to be clean and of good quality. For classification purposes, samples were selected by taking portions of a number of bags.

When the testing program was enlarged (see Chapter 2) additional supplies were obtained from the same stockpiles and samples obtained in the forementioned manner. Results of classification tests on this second supply differ from those on the first by small amounts within the limits of experimental error.

4.1.1.1. Coarse Aggregate

Coarse aggregate was 3/4 inch maximum size crushed and washed rock, known commercially as slab aggregate. The

3/4 inch size was selected in accordance with A.S.T.M. Standard C192-55 which requires that "The minimum cross-sectional dimension shall be at least three times the maximum nominal size of coarse aggregate." For the three inch cross-sectional dimensions of this investigation, a maximum coarse aggregate size of 3/4 inch is therefore within the A.S.T.M. requirements.

4.1.1.2. Physical Properties of Aggregates

Sieve analyses were made in accordance with A.S.T.M. Standard C131-46. Determinations of the material passing the #200 sieve were made in accordance with A.S.T.M. Standard C117-47 (washed analyses). For sieve analyses results see Appendix A, Fig.1.

Additional physical properties of the aggregates are presented in Appendix A, Table 1..

4.1.2 CEMENT

Type 1 Portland cement was used for all mixes. Again enlargement of the test program resulted in two supplies. Uniformity in each supply was achieved by taking consecutive bags from a bin. The only check on the uniformity between supplies is in the form of compression strength tests (cubes) formed from each supply in accordance with C.S.A. Specifications A 5. Average results are presented overleaf.

COMPRESSIVE STRENGTH OF CEMENT CUBES

Compressive Strengths

	3 Day	7 Day	28 Day
Supply 1	1,450 psi	2,980 psi	4,050 psi
Supply 2	1,580 psi	2,560 psi	3,200 psi
C.S.A. A5 Minimum Strengths	900 psi	1,800 psi	3,000 psi

Note - water added equal to 58% by weight of the cement

- flow = 100%

The manufacturer supplied the following average values for this cement:

Fineness - 3,100 cm. ²/gm. Blaine
 Specific Gravity - 3.15
 Normal Consistency - 24% to 25%

The above are general published values and were not determined by tests on either cement supply used in this investigation.

4.1.3. MIXING WATER

Mixing water was taken directly from the City of Edmonton mains. Its temperature was approximately 70° F.

4.2 MIX PROPORTIONS

Mix proportions were determined using recommendations of A.C.I. 613-54 based upon a 1 inch to 2 inch slump.

Preliminary mixes were designed for 3,000 psi, 4,000 psi and 5,000 psi 28 day compressive strengths. Seven day trial tests on cylinders from the preliminary mixes indicated that strengths much in excess of the design strengths could be expected. The possibility of aggregate failure controlling the strength of test cylinders should be avoided in an investigation which attempts to show strength increases under special conditions. Therefore, 2,000 psi, 3,000 psi, and 4,000 psi design proportions were used for the final mixes.

The final mix proportions are shown in Appendix A, Table 2. Since aggregates were dried before use, the design weight of water was corrected for aggregate absorption. Small reductions were necessary in the design weight of water to keep the slump below 2 inches. The basic properties of the mixes are summarized below.

BASIC MIX DESIGN PROPERTIES

Property	28 Day Design Strengths		
	2,000 psi	3,000 psi	4,000 psi
Water - Cement Ratio gal/bag	7.0	5.65	4.65
Cement Factor bag/cu.yd.	4.20	5.21	6.33
28 Day Test Strength psi	2,480	4,110	5,370

Since only relative values are to be used in computing test results, the increased strength over design

values is of no significance. However, it must be noted that 2,000 psi, 3,000 psi, and 4,000 psi designs referred to in other parts of this dissertation actually refer to the above 28 day strengths.

4.3. MANUFACTURE OF SPECIMENS

4.3.1. MIXING OPERATION

4.3.1.1. Preparation of Materials

Coarse and fine aggregates were transported from the stockpiles and stored in bags. Prior to mixing, the necessary volumes were selected and dried in ovens to obtain a uniform moisture content. Upon removal from the ovens, the volume of each type of aggregate was intermixed in a pile and allowed to cool before being used in the mix.

Cement was taken directly from the bags. Due to storing in a dry location, no lumping was encountered.

4.3.1.2. Batching

The complete volume of concrete of a design strength required for the specimens of a particular test temperature was mixed in one batch. A batch consisted of sufficient concrete (with some excess) to mold the following specimens:

- i) 24 cylinders of each of the 3 design mixes, making a total of 72 cylinders.
- ii) 12 beams of each design mix, making a total of 36 beams.

The total volume was about two cubic feet for each design mix. In addition, 12 cylinders of each strength were poured as additional control cylinders for the three batches of the expanded test program. Batch numbers and corresponding test temperatures are shown in Table 1.

All mix components were weighed in tared containers to an accuracy of 0.1 pounds.

4.3.1.3 Mixing

The $3\frac{1}{2}$ cubic foot tilting drum mixer was used throughout this investigation. It was prepared by the mixing of a $\frac{1}{4}$ cubic foot "butter mix" of 2,000 psi design proportions prior to the mixing of a batch.

The mixer was charged while stationary with coarse aggregate, fine aggregate, and cement, in that order. Water was added slowly while the mixer was turning. The total mixing time in all cases was $2\frac{1}{2}$ minutes. The concrete was then dumped into a trough and the slump checked.

For each batch, mixing was in the following order; 2,000 psi, 3,000 psi, 4,000 psi design. A record of mixing is shown in table 1.

4.3.2. CASTING SPECIMENS

4.3.2.1. Specimen Molds

Cylinder molds were of commercial design consisting of a waxed cardboard tube of 3 inch inside diameter; no significant variation in diameter was noted for specimens from these molds.

TABLE 1
RECORD OF MIXING

Batch	Test Temp. °F	Date of Pour	Design Strength p.s.i.	Measured Slump inches	Remarks
1.	-30	July 4	2,000 3,000 4,000	1 2 2½	
2.	0	July 6	2,000 3,000 4,000	1 1¼ 1	Harsh mix due to warm sand
3.	+35	July 8	2,000 3,000 4,000	1½ 1¼ 1	
4.	+70	July 12	2,000 3,000 4,000	2 1½ 1	
7.	-15 Special	July 29	2,000 3,000 4,000	1 1½ 1	Reduced moisture content tests
8.	+15	Aug. 18	2,000 3,000 4,000	1½ 1½ 1½	
9.	-15	Aug. 19	2,000 3,000 4,000	2 1 1	
10.	+50	Sept. 6	2,000 3,000 4,000	1½ 1½ 1½	Low slump

The plan of the beam molds is shown in Appendix A, Fig. 2. Basically, they are of 3/4 inch waterproofed plywood construction with provisions for four 3 inch by 3 inch by 18 inch specimens in each mold. Molds were oiled before the concrete was cast. The set of molds was reused for each batch. Some variation in the cross sectional dimensions of the beams was obtained; correction was made for this in computations.

4.3.2.2. Casting

Cylinders were cast in accordance with A.S.T.M. Standard C192-55, paragraph 9, except that a 3/8 inch diameter rod was substituted for the standard 5/8 inch diameter rod. This substitution was necessary because preliminary tests indicated the larger diameter rod, coupled with 3/4 inch aggregate and low slump in the small mold, produced more of a ramming than rodding effect. The sides of the cylinders were tapped slightly with the rod to reduce voids,. In general, exceptionally few voids were found.

Beams were cast in accordance with A.S.T.M. Standard C192-55, paragraph 14, using 27 roddings in each of two layers. The mold partitions were tapped lightly with a hammer. Voids were obtained at the bottom corners of all specimens and a few were obtained in the center sections. In the few cases where test failure took place through voids, the results were discarded.

4.4. CURING OF SPECIMENS

After casting, specimens were allowed to set for about 4 hours and then covered with wet burlap for the next 20 hours. The burlap was sprayed once during this 20 hour interval. Following the first 24 hour period, the molds were stripped, and the samples marked and stored in the moist room.

Some fluctuations in curing conditions occurred while specimens were in the moist room. Most, but not all, specimens were under direct water spray. Moist room temperatures fluctuated between 68°F and 78°F. It is felt that these fluctuations were not sufficient to cause significant differences in test results.

At some convenient time prior to their test age, cylinders were removed from the moist room, capped with sulphur and returned to the moist room.

4.5. AUXILIARY TESTING

Two sets of auxiliary tests were performed at a temperature of -30°F to check the effect of moisture content on strength at low temperatures.

- i) 2,000 and 4,000 psi design proportions were mixed with 10 percent by weight of water.

No cement was added. Four cylinders of each batch were poured.

- ii) Extra cylinders from batch 4 were moist cured for eight and one-half months and subjected to 48 hours' conditioning, as noted in Sect.5.1. One cylinder of both 2,000 and 4,000 psi design was,
 - a) left in the moist room,
 - b) immersed in water,
 - c) oven dried at 230° F.

All specimens were tested by loading to the ultimate load in the manner defined in A.S.T.M. Standard C39.

CHAPTER 5

TESTING

Where possible testing was in accordance with standard methods. Some deviations from standard procedure were necessary in order to cool specimens to their test temperature.

5.1 COOLING SPECIMENS

All specimens, except those for standard tests, were cooled in the Frost Room. The temperature was controlled by a coarse thermostat. Actual specimen temperatures were obtained by connecting thermocouples from the Frost Room to an automatic temperature recorder which gave continuous time-temperature charts for cooling and testing periods.

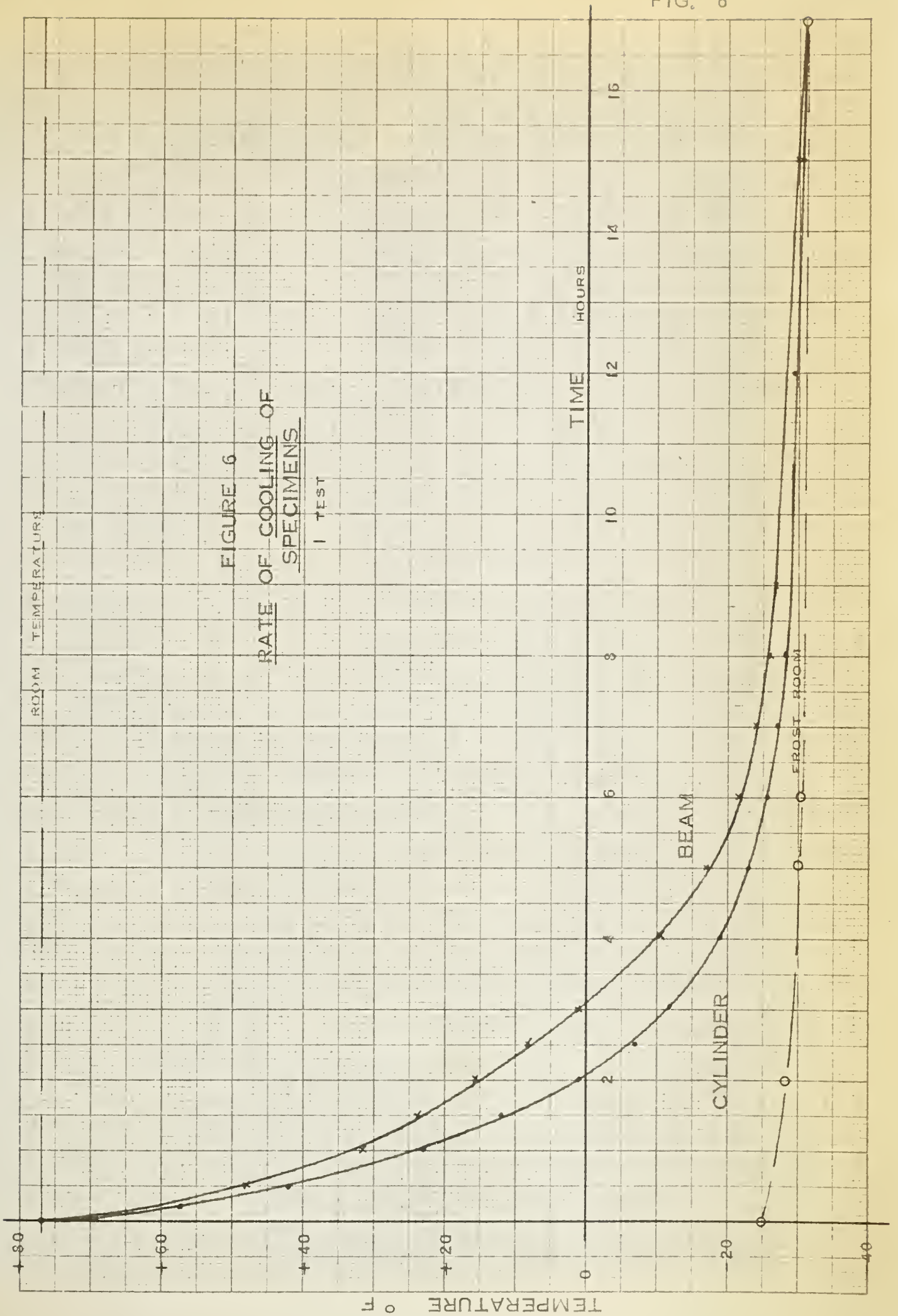
During preliminary testing, thermocouples were cast in the centers of some beams and cylinders. The time-temperature relationship for these specimens is shown in Fig. 6. It was felt that 20 hours cooling time would be necessary to guarantee that specimens would reach equilibrium at -30°F .

To obtain a uniform conditioning time, beams and cylinders were subjected to 20 hours cooling time for all test temperatures. The following conditioning procedure was adopted.

1. 2 days prior to a test date, the Frost Room was cooled to the particular test temperature.

2. 1 day prior to the date, the beams and cylinders to be tested were removed from the moist room, allowed to

FIG. 6



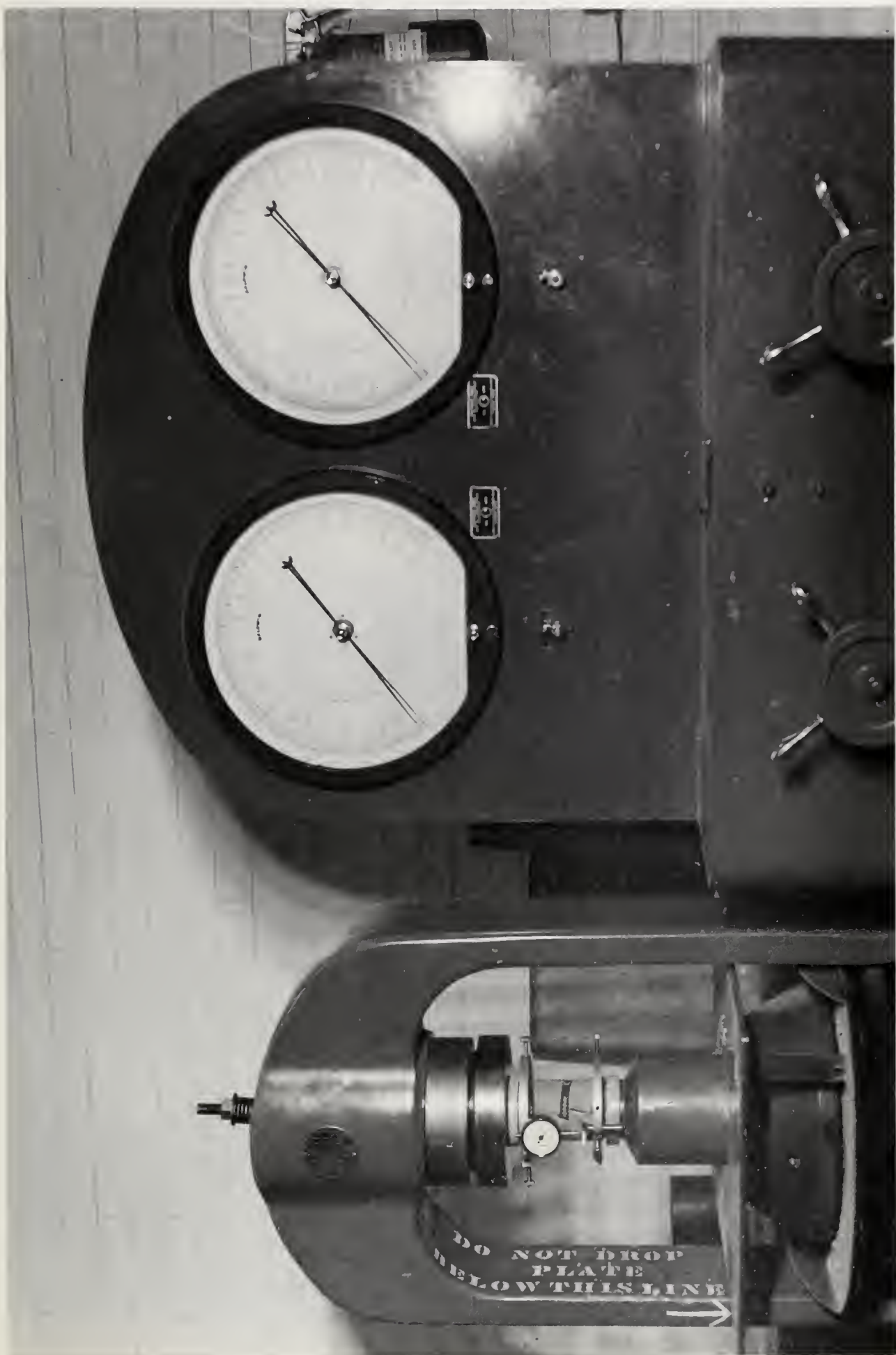


Plate 1

CYLINDER TEST IN BALDWIN TESTER

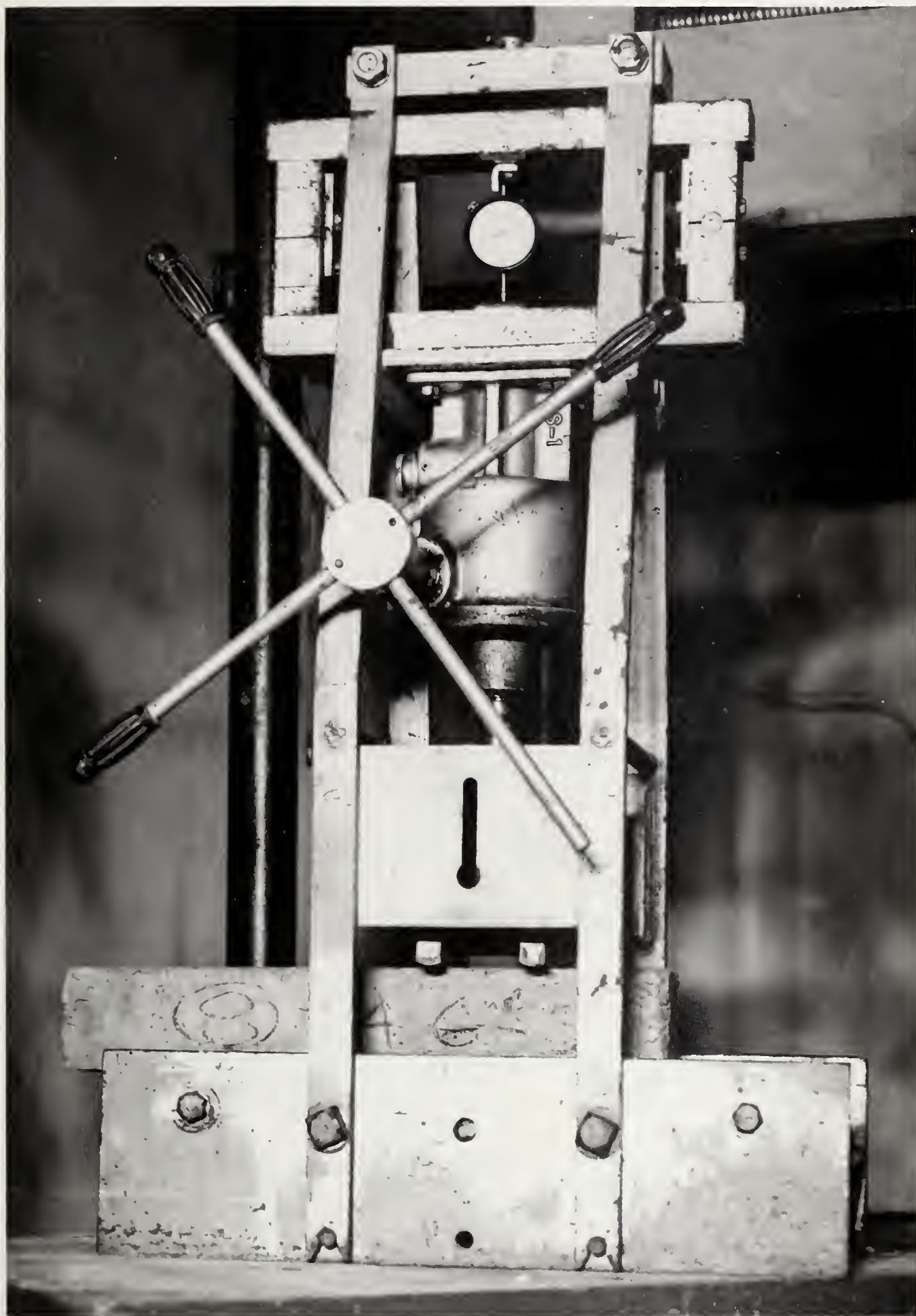


Plate 2 BEAM TESTER

surface dry at room temperature and were then placed in the Frost Room. The automatic temperature recorder was started at this time.

3. Testing began about 20 hours after the specimens were put in the Frost Room.

5.2 TEST APPARATUS

5.2.1. Compression Tests

All compression tests were performed on the Baldwin 300,000 pound hydraulic testing machine (see Plate 1.)

5.2.2. Flexural Tests

All beams were tested on the American Beam Tester #85 (see Plate 2), with which load is applied manually and is measured as some function of the center deflection of the proving beam. Deflection was measured with a Mercer 0.0001 inch dial. Calibration of the proving beam is shown in Appendix A. Fig. 3.

The beam tester was manufactured to handle standard 6 inch by 6 inch by 36 inch flexural specimens. For the 3 inch by 3 inch by 18 inch beams used in this investigation, a scaled down version of the original loading head and new reaction points were adapted to give a one-third point loading on a 9 inch beam test length. The advantage of this type of beam tester lay in the fact that it could be operated in the Frost Room.

5.2.3. Strain Measurements

The strain of the cylinders during loading in the

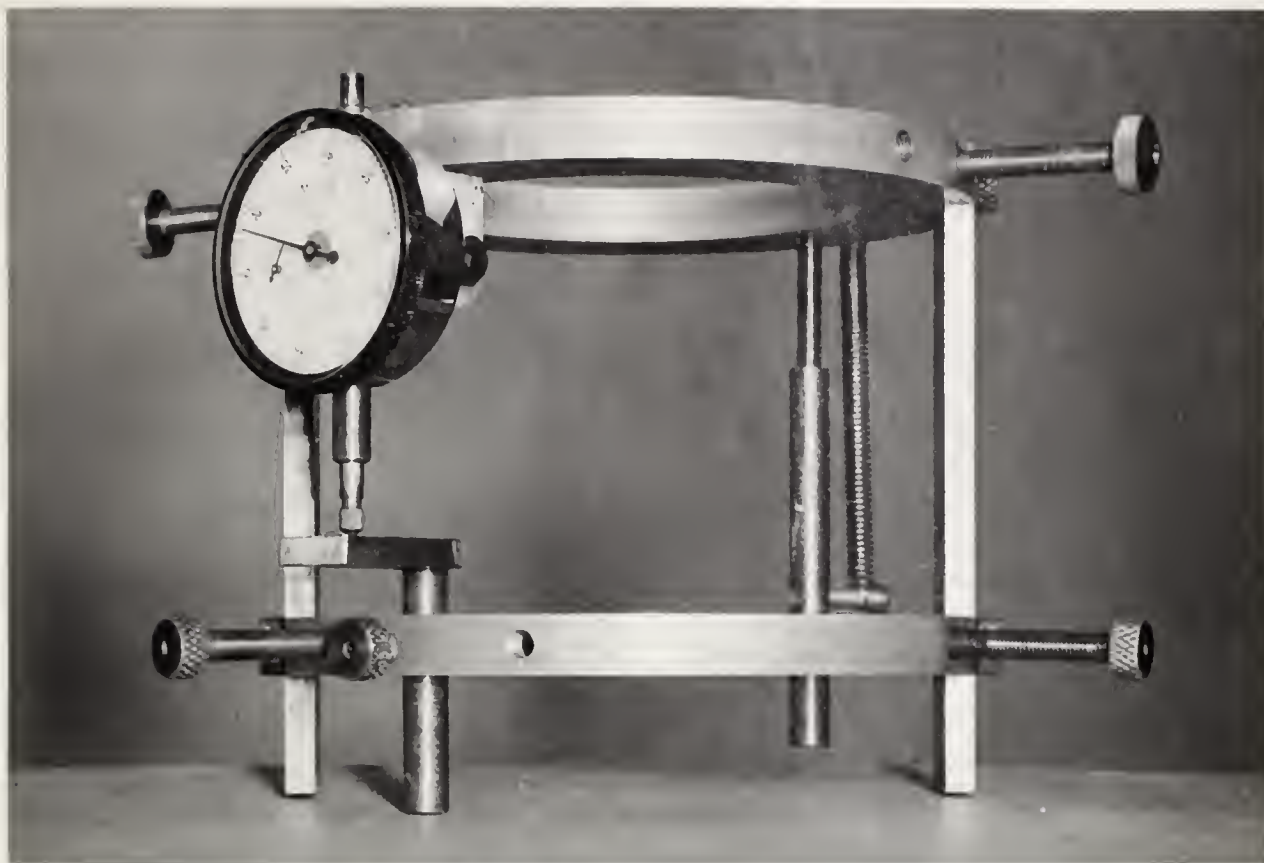


Plate 3 A Compressometer with Gauge Bars

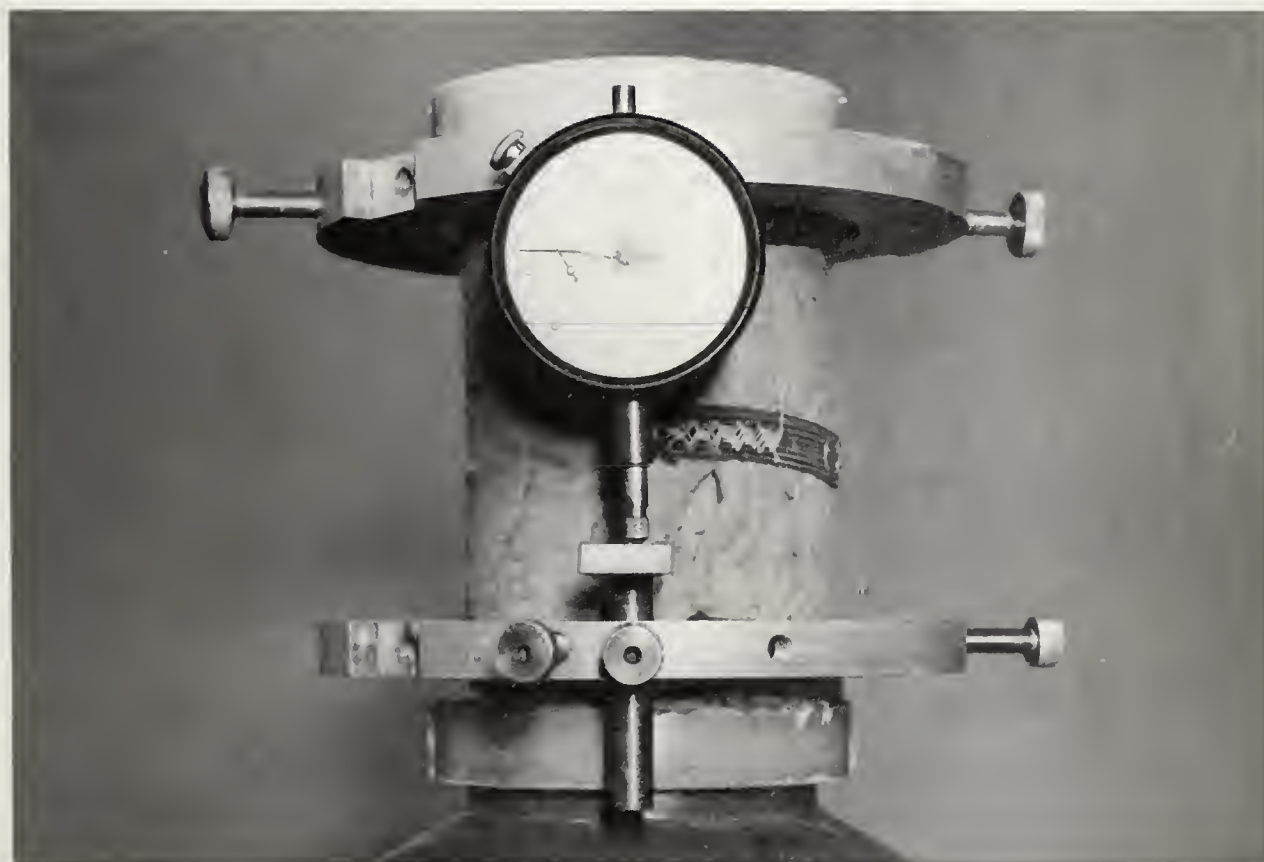


Plate 3 B Compressometer with Jacketed Cylinder
Ready for Testing

compression machine was measured with a collar compressometer over a 4 inch gauge length. Details of the compressometer are shown in Appendix A Fig. 4 and in Plate 3. A Mercer 0.0001 inch dial was used to measure strain.

An error in manufacture of the compressometer resulted in the upper contact points not being placed on a diameter perpendicular to the hinge and dial. Calibration was performed on a 3 inch diameter by 6 inch bakelite cylinder; results indicated that it would give accurate, reproducible values of strain except for dial readings less than about 0.0025 inches (unit strain of about 0.00025.) For these low strains, some stickiness in the compressometer mechanism resulted in low dial readings. This error was later evidenced by strain readings on concrete cores which showed a pronounced linear stress - unit strain relationship for unit strains greater than about 0.00025.

Other investigators such as Walker and Hollister (20) and Blackman (37) have also noted pronounced initial curvature. Walker measured strains with an instrument almost identical to the compressometer described above. It is felt that the initial curvature is an instrumental error rather than an intrinsic property of the stress - strain relationship of concrete.

There is a possibility that strains measured on a 4 inch gauge length for 6 inch specimens might be influenced by end effects. Teller (38) stated, "The gauge length preferably should not exceed one-half the length of the specimen."

However, for these tests the advantage of increased precision with measurements on a longer gauge length would probably outweigh the possibility of any end effect error.

5.3 TESTING PROCEDURE

5.3.1. Cylinders

After the 20 hour cooling period, cylinders were wrapped in felt jackets in preparation for testing. Each specimen in turn was removed from the Frost Room, placed in the compressometer and then in the compression machine as quickly as possible. (See Plate 1.) A continuous loading rate of 30 p.s.i. per second (see A.S.T.M. C39-49) was applied to ultimate load. Compressometer readings were taken at convenient, even increments. After ultimate load was reached, the cylinder was removed from the compressometer, its jacket removed and its diameter measured.

The total time of test from removal from the Frost Room to ultimate load varied as the cylinder strength, being about 7 minutes for the highest strengths and 4 minutes for the lowest. Although it is realized that cylinder temperatures rose during testing, no attempt will be made to apply a correction; therefore, the test temperature given for any cylinder is its temperature upon removal from the Frost Room. Warm-up readings of the thermocouple installations described in 5.1 indicated that the temperature of the center of the

cylinders rose about 1° per minute from an initial temperature of -30° F.

The standard specimens were removed from the moist room and tested directly.

Arbitrarily selected specimens for each design strength were immediately loaded to complete failure after diameter measurements. The failure pattern was observed and moisture content samples obtained. Usually 2 of the 6 cylinders of each strength were tested in this manner.

5.3.2. Beams

Beams were tested in accordance with A.S.T.M. C78-49. Rapid load was applied to about 50% of ultimate load and the remainder at a continuous rate of about 50 p.s.i. per minute. Only values of ultimate load were taken. Two breaks were made on each beam.

After failure the beam depth and width at the failure section and the type of failure were noted. Portions of the broken beam were used as moisture content samples.

5.3.3. Modified Cubes *

The center portion of each broken beam was retained for the modified cube test. Specimens were trimmed to size with a diamond saw and allowed to soak in water at about 65° F for 24 hours. The specimens were then measured and

* Specimens referred to as modified cubes in this investigation are not the same as defined by the Modified Cube Test of A.S.T.M. C116. The A.S.T.M. test uses portions of broken beams tested in compression without any cutting to the cubic shape.

loaded to ultimate load in compression perpendicular to the direction of molding. A continuous loading rate of 40 p.s.i.per second was used in accordance with A.S.T.M. C116-49.

5.3.4. Moisture Contents

The portions of the beams and cylinders for moisture content samples were weighed immediately after testing and placed in an oven at about 220° F. The dry weight was determined after 48 hours drying.

CHAPTER 6

T E S T R E S U L T S

The testing program was conducted as described in Chapter 5. The test results are presented in tabular and graphical form in subsequent sections.

6.1. NUMERICAL RESULTS

Complete tabulation of the average test results, with the exception of the results of the Auxiliary Testing, is presented in Tables 2A to 2D. The numerical values were obtained from the summary data sheets of Appendix B. The original data sheets are not included because of their large volume.

Generally, all strength test values in Tables 2A to 2D are the average of six individual tests. In a few cases, a test value was rejected due to significant physical defects in the specimen or due to non-conformity of a test value with the values from the other specimens of the group. Rejection on the basis of non-conformity was controlled by statistical analysis computations as indicated at the beginning of Appendix B.

TABLE 2 A
7 DAY TEST RESULTS SUMMARY

2,000 PSI DESIGN				3,000 PSI DESIGN				
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS X 10 ⁶ PSI	CHORD MODULUS X 10 ⁶ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS X 10 ⁶ PSI	CHORD MODULUS X 10 ⁶ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI
5,990 -33 450	1,470 -28 9.6 955	4.7 215	3.8 240	7,430 -31 320	1,550 -28 601	4.8 200	3.7 200	8,370 -32 264
4,850 -18 8.2 365	1,515 -19 7.6 984	4.4 245	3.8 240	5,970 -18 257	1,425 -18 8.3 554	4.3 190	3.3 180	7,390 -18 6.8 233
				NO SAMPLES				
4,510 -2 339	1,570 +2 1,020	4.1 185	3.2 200	5,440 -2 234	1,570 0 609	4.3 180	3.2 180	6,390 -2 202
3,490 +13 262	1,260 +14 7.2 818	3.3 150	1.4 90	4,310 +13 7.3 186	1,370 +14 7.1 531	3.2 135	2.2 120	4,900 +13 6.6 155
2,040 +26 153	362 +31 235	1.9 85	1.3 80	2,730 +28 118	446 +29 173	2.3 95	1.6 90	3,470 +29 109
1,280 +49 7.1 96.2	147 +49 7.0 95.5	1.5 70	1.0 65	2,170 +49 8.6 93.5	223 +49 86.4 80	1.9 80	1.5 85	3,510 +49 6.9 104
1,330 +78 100	154 +72 100	2.2 100	1.6 100	2,320 +78 100	258 +72 100	2.4 100	1.8 100	3,170 +78 100

4,000 PSI DESIGN					BATCH
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS x 10 ⁶ PSI	CHORD MODULUS x 10 ⁶ PSI		
8,370 -32 264	1,455 -28 401	4.7 180	3.5 165	1. [-30 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
7,390 -18 6.8 233	1,400 -18 6.5 386	4.3 145	2.9 140	9. [-15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
				7. [-15 F] SPECIAL TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
6,390 -2 202	1,350 +2 372	4.0 155	3.1 150	2. [0 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
4,900 +13 6.6 155	1,200 +14 6.1 331	3.1 120	2.3 110	8. [+15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
3,470 +29 109	474 +29 131	2.6 100	2.2 110	11. [+35 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
3,510 +49 6.9 104	316 +49 6.1 87.3	2.5 95	2.0 95	10. [+50 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	
3,170 +78 100	362 +72 100	2.6 100	2.1 100	4. STANDARD TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD	

TABLE 2 B
28 DAY TEST RESULTS SUMMARY

2,000 PSI DESIGN				3,000 PSI DESIGN				4,000 PSI DESIGN	
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI
7,130 -31 287	1,540 -22 7.1 537	4.5 185	3.0 160	8,570 -31 209	1,280 -21 294	4.3 130	2.9 110	10,100 -30 6.8 188	1,280 -21 294
5,250 -18 212	1,360 -18 474	3.9 160	2.8 145	7,850 -18 191	1,390 -18 320	4.3 130	3.4 125	9,700 -18 181	1,390 -18 320
5,520 -18 223	989 -18 5.0 345			7,410 -19 5.4 180	1,140 -18 4.2 263			9,030 -20 5.2 168	1,140 -18 4.2 263
5,120 0 7.1 206	1,340 +6 6.7 467	4.8 200	3.4 180	6,710 +1 7.3 163	1,455 +2 335	4.3 135	3.2 120	8,300 +1 155	1,455 +2 335
4,370 +13 6.6 176	1,250 +13 6.9 436	3.3 140	2.6 135	5,940 +13 7.3 145	1,210 +13 6.9 279	3.6 110	2.9 110	6,870 +16 128	1,210 +13 6.9 279
2,700 +33 6.3 147	317 +32 6.1 110	2.8 115	2.2 140	3,880 +31 6.2 94.4	363 +32 5.5 83.6	3.2 100	2.6 95	5,060 +30 5.2 94.2	363 +32 5.5 83.6
2,650 +49 6.9 107	311 +49 6.4 108	2.8 115	2.1 110	3,510 +49 7.0 85.3	319 +49 6.8 73.5	2.8 90	2.2 80	4,870 +49 6.2 90.7	319 +49 6.8 73.5
2,480 +77 6.2 100	287 +75 5.6 100	2.4 100	1.9 100	4,110 +77 6.1 100	434 +75 4.7 100	3.2 100	2.7 100	5,370 +77 5.6 100	434 +75 4.7 100

4,000 PSI DESIGN				BATCH
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	
10,100 -30 6.8 188	1,300 -18 6.1 248	4.1 125	3.6 135	1. [-30 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
9,700 -18 181	1,380 -18 263	4.4 140	3.5 130	9. [-15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
9,030 -20 5.2 168	1,060 -18 4.2 202			7. [-15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
8,300 +1 155	1,460 +3 5.0 279	4.6 145	3.7 140	2. [0 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
6,870 +16 128	1,210 +13 5.7 250	3.7 115	3.1 115	8. [+15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
5,060 +30 5.2 94.2	496 +29 5.5 94.6	3.5 110	2.9 110	3. [+35 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
4,870 +49 6.2 90.7	429 +49 6.3 81.9	3.2 100	2.7 100	10. [+50 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
5,370 +77 5.6 100	524 +75 3.8 100	3.2 100	2.7 100	4. STANDARD TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD

TABLE 2 C

2 MONTH TEST RESULTS SUMMARY

2,000 PSI DESIGN				3,000 PSI DESIGN				ULTIMATE COMPRESSIVE STRENGTH PSI
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS X 10 ⁶ PSI	CHORD MODULUS X 10 ⁶ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS X 10 ⁶ PSI	CHORD MODULUS X 10 ⁶ PSI	
7,160 -29 8.1 269	1,650 -29 6.8 591	4.1 150	2.9 140	8,950 -30 7.0 198	1,520 -28 375	4.0 115	2.9 100	10,420 -31 4.9 181
6,820 -16 7.4 256	1,560 -16 7.6 559	3.9 145	3.0 145	8,250 -16 6.9 175	1,420 -15 6.5 341	4.1 115	3.1 105	9,590 -16 7.3 166
3,950 -18 -1.1 148	527 -18 0.16 189			6,380 -18 0.9 141	791 -18 0.16 190			8,440 -18 1.5 147
OVEN DRY AT + 230 DEGREES F								
5,750 -1 6.6 216	1,520 -1 6.5 545	4.6 170	3.7 175	7,640 -2 6.2 169	1,470 -1 6.0 354	4.7 135	3.8 130	9,390 -2 6.0 163
4,990 +14 7.4 188	1,280 +14 7.0 459	3.6 135	2.7 130	6,480 +13 7.1 143	1,180 +15 5.9 283	3.8 110	3.1 105	8,255 +14 6.6 143
2,780 +34 8.4 105	309 +34 6.8 111	3.2 120	2.2 105	3,890 +34 6.3 86.0	424 +34 6.3 96.0	3.8 110	3.2 110	5,540 +34 5.8 96.2
2,860 +49 6.4 108	285 +49 6.3 102	2.5 95	1.9 90	4,230 +49 6.6 93.6	275 +49 5.8 66.1	2.8 80	2.3 80	5,240 +49 6.3 91.0
2,660 6.1 100	279 6.3 100	2.7 100	2.1 100	4,520 6.1 100	416 6.0 100	3.5 100	2.9 100	5,760 6.0 100

4,000 PSI DESIGN

ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	BATCH
10,420 -31 4.9 181	1,430 -28 285	4.2 125	3.0 100	1. [-30 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
9,590 -16 7.3 166	1,600 -11 319	4.5 130	3.7 120	9. [-15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
8,440 -18 1.5 147	828 -18 0.19 165			7. [-15 F] SPECIAL TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
9,390 -2 6.0 163	1,470 0 5.6 293	4.8 140	3.9 130	2. [0 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
8,255 +14 6.6 143	1,290 +15 6.2 257	4.2 125	3.5 115	8. [+15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
5,540 +34 5.8 96.2	459 +34 5.8 91.5	3.9 115	3.4 110	3. [+35 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
5,240 +49 6.3 91.0	401 +49 5.7 80.0	3.1	2.6	10. [+50 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD
5,760 6.0 100	502 5.7 100	3.4 100	3.0 100	4. STANDARD TEST VALUE TEST TEMP. F MOISTURE CONTENT % % OF STANDARD

TABLE 2 D

4 MONTH TEST RESULT SUMMARY

2,000 PSI DESIGN				3,000 PSI DESIGN			
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI
7,080 -28 7.2 251	1,800 -28 6.9 625	4.2 135	3.0 125	9,375 -30 8.9 214	1,515 -30 5.7 339	4.3 120	3.2 120
6,540 -17 232	1,460 -16 7.3 507	4.2 135	3.0 125	8,860 -17 203	1,460 -15 6.2 327	4.3 120	3.0 110
6,220 -18 2.8 221	991 -18 2.4 344			7,885 -18 5.7 180	980 -18 5.0 219		
SAMPLES AIR DRY 4 DAYS							
5,970 -1 6.7 212	1,550 -1 7.1 538	4.8 155	3.8 160	8,020 -1 6.3 183	1,660 -1 6.2 371	4.6 130	3.2 120
4,920 +15 7.6 174	1,390 +12 6.9 483	3.9 125	2.8 115	6,350 +15 7.4 145	1,340 +15 7.3 300	4.1 115	3.2 120
3,140 +31 6.4 111	343 +31 7.0 119	2.9 95	2.1 90	4,410 +31 6.3 94.7	438 +31 6.7 98.0	3.7 105	2.9 110
2,870 +49 102	343 +49 6.5 119	3.1 100	2.3 95	4,360 +49 99.8	466 +49 6.3 104	3.6 100	2.7 100
2,820 +74 7.7 100	288 +74 7.6 100	3.1 100	2.4 100	4,370 +74 7.1 100	447 +74 7.1 100	3.6 100	2.7 100

4,000 PSI DESIGN				BATCH
ULTIMATE COMPRESSIVE STRENGTH PSI	MODULUS OF RUPTURE PSI	SECANT MODULUS $\times 10^6$ PSI	CHORD MODULUS $\times 10^6$ PSI	
9,840 -30 5.9 176	1,300 -29 5.1 236	4.3 115	3.5 120	1. [-30 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
9,980 -17 178	1,400 -13 6.4 305	4.8 130	3.8 130	9. [-15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
8,320 -17 5.5 166	930 -18 5.6 169			7. [-15 F] SPECIAL TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
9,220 -1 6.1 165	1,570 -1 5.9 285	4.9 130	4.0 140	2. [0 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
7,710 +14 6.6 138	1,210 +17 6.2 220	4.4 120	3.5 120	8. [+15 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
5,860 +31 6.4 105	555 +31 6.4 101	4.0 110	3.2 110	3. [+35 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
5,710 +49 102	517 +49 6.1 93.9	3.9 105	3.5 120	10. [+50 F] TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD
5,600 +74 7.4 100	550 +74 7.3 100	3.7 100	2.9 100	4. STANDARD TEST VALUE TEST TEMP. F MOISTURE CONTENT % % STANDARD

Values of the secant and chord moduli of elasticity were obtained from the stress-strain curves of Appendix C by the method defined in Section 6.7.

In order to present relative values, the test results of Tables 2A to 2D are expressed as a percentage of the standard specimen (Batch 4) test results.

The results of a statistical analysis on the strength tests are presented in Tables 3A to 3D. The average strength test results, $\bar{X}$, are identical to those indicated in Tables 2A to 2D; values of n indicate the number of individual test values used for each computation; the standard deviation, S.D.*, is the root-mean-square deviation of the test values from their average and is used as a measure of the dispersion of the test results; the coefficient of variation, C.V., is the standard deviation expressed as a percentage of the average test result; the range, R , is the arithmetic difference between the highest and lowest test value in each group. The methods of computation for the statistical analysis are indicated at the beginning of Appendix B.

The average values of the coefficient of variation for various arrangements of the test results are shown in

*The standard deviation is generally symbolized by the Greek letter sigma (σ), but, due to the small number of values in each group of this investigation necessitating a special form of the standard deviation, the symbol S.D. was adopted.

7 DAY TESTING STATISTICAL ANALYSIS SUMMARY

2,000 PSI		3,000 PSI		4,000 PSI		BATCH
ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	
5,990	1,470	7,430	1,550	8,370	1,455	1. $\bar{X}$ PSI
6	5	6	5	6	6	N
280	270	260	86	200	160	S. D. PSI
4.7	18.0	5.5	5.6	2.4	11.2	C. V. %
830	650	710	210	550	400	R PSI
4,850	1,515	5,970	1,425	7,390	1,450	9. $\bar{X}$ PSI
5	6	6	6	6	6	N
350	150	110	175	330	110	S. D. PSI
7.3	10.1	1.8	12.2	4.4	7.7	C. V. %
900	400	300	510	850	330	R PSI
						7. No SPECIMENS
4,510	1,570	5,440	1,570	6,390	1,350	2. $\bar{X}$ PSI
6	6	6	6	6	6	N
150	150	280	35	160	110	S. D. PSI
3.4	9.8	5.1	2.2	2.5	8.2	C. V. %
410	420	590	90	450	310	R PSI
3,490	1,260	4,310	1,370	4,900	1,200	8. $\bar{X}$ PSI
6	6	5	5	6	6	N
130	93	190	125	290	79	S. D. PSI
3.8	7.4	4.3	9.1	6.0	6.6	C. V. %
370	290	420	320	830	190	R PSI
2,040	362	2,730	466	3,470	474	3. $\bar{X}$ PSI
6	6	6	5	6	6	N
56	53	63	20	180	13	S. D. PSI
2.8	14.6	2.3	4.4	5.2	2.8	C. V. %
150	140	185	50	510	33	R PSI
1,280	147	2,170	223	3,510	316	10. $\bar{X}$ PSI
6	4	6	6	5	6	N
100	11	135	22	200	33	S. D. PSI
7.8	7.7	6.2	10.0	5.7	10.6	C. V. %
260	19	330	66	470	98	R PSI
1,330	154	2,320	258	3,170	362	4. $\bar{X}$ PSI
6	6	6	6	6	6	N
70	14	70	14	190	28	S. D. PSI
5.3	9.4	3.0	5.3	5.6	7.6	C. V. %
190	35	195	36	460	73	R PSI

TABLE 3 B

28 DAY TESTING STATISTICAL ANALYSIS SUMMARY

2,000 PSI		3,000 PSI		4,000 PSI		BATCH
ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	
7,130	1,540	8,570	1,280	10,100	1,300	1. $\bar{X}$ PSI
6	6	6	4	5	6	N
470	52	330	29	400	110	S. D. PSI
6.5	3.4	3.8	3.0	4.0	8.6	C. V. $\%$
1,280	140	580	180	960	240	R PSI
5,250	1,360	7,850	1,390	9,700	1,380	9. $\bar{X}$ PSI
6	6	6	6	6	6	N
730	85	130	70	280	110	S. D. PSI
14.0	6.3	1.7	5.0	2.9	8.0	C. V. $\%$
2,020	180	330	190	710	270	R PSI
5,520	989	7,410	1,140	9,030	1,060	7. $\bar{X}$ PSI
6	6	6	6	6	6	N
200	190	240	47	130	69	S. D. PSI
3.6	19.0	3.2	4.1	1.5	6.5	C. V. $\%$
580	350	660	130	300	170	R PSI
5,120	1,340	6,710	1,450	8,300	1,460	2. $\bar{X}$ PSI
6	6	6	6	5	6	N
190	140	200	78	170	110	S. D. PSI
3.8	10.7	3.0	5.3	2.0	7.4	C. V. $\%$
560	340	480	200	440	210	R PSI
4,370	1,250	5,940	1,210	6,870	1,210	8. $\bar{X}$ PSI
6	6	6	6	6	5	N
93	66	360	125	210	87	S. D. PSI
2.1	5.3	6.1	10.3	3.0	7.2	C. V. $\%$
240	180	980	220	540	210	R PSI
2,700	317	3,880	363	5,060	496	3. $\bar{X}$ PSI
5	6	5	6	6	6	N
79	34	240	31	400	20	S. D. PSI
2.9	10.7	6.2	8.6	8.0	4.0	C. V. $\%$
100	81	620	57	920	36	R PSI
2,650	311	3,510	319	4,870	430	10. $\bar{X}$ PSI
6	5	6	6	6	6	N
165	50	300	53	630	39	S. D. PSI
6.2	16.1	8.4	16.6	13.0	9.2	C. V. $\%$
260	68	800	116	1,820	113	R PSI
2,480	287	4,110	434	5,370	524	4. $\bar{X}$ PSI
6	6	6	6	6	6	N
170	28	290	15	180	30	S. D. PSI
6.8	9.8	7.1	3.4	3.4	5.7	C. V. $\%$
440	70	730	41	500	74	R PSI

56 DAY TESTING STATISTICAL ANALYSIS SUMMARY

2,000 PSI		3,000 PSI		4,000 PSI		BATCH
ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	
7,160	1,650	8,950	1,520	10,420	1,430	1. $\bar{X}$ PSI
5	6	6	5	6	6	N
160	55	250	18	330	96	S.D. PSI
2.2	3.3	2.8	1.2	3.2	6.7	C.V. %
460	150	720	40	830	280	R PSI
6,820	1,560	8,250	1,420	9,590	1,400	9. $\bar{X}$ PSI
6	6	5	6	6	6	N
230	100	280	180	570	160	S.D. PSI
3.4	6.6	3.4	12.7	5.9	11.1	C.V. %
560	290	620	230	1,540	230	R PSI
3,950	526	6,380	791	8,440	828	7. $\bar{X}$ PSI
6	6	6	6	5	6	N
175	44	220	50	270	78	S.D. PSI
4.4	8.4	3.4	6.4	3.3	9.4	C.V. %
490	170	550	115	760	220	R PSI
5,750	1,520	7,640	1,480	9,390	1,470	2. $\bar{X}$ PSI
4	6	6	6	6	4	N
	75	270	110	260	97	S.D. PSI
	4.9	3.6	7.2	2.7	6.6	C.V. %
	180	550	330	700	210	R PSI
4,990	1,280	6,480	1,180	8,250	1,290	8. $\bar{X}$ PSI
6	6	6	6	6	6	N
300	120	240	110	210	100	S.D. PSI
6.1	9.5	3.7	9.7	2.6	7.9	C.V. %
840	360	660	310	560	290	R PSI
2,780	309	3,890	424	5,540	459	3. $\bar{X}$ PSI
6	6	6	5	6	6	N
150	51	210	26	380	32	S.D. PSI
5.5	16.6	5.5	6.1	7.0	7.1	C.V. %
440	160	610	61	930	80	R PSI
2,860	285	4,230	275	5,240	401	10. $\bar{X}$ PSI
5	4	6	6	6	6	N
140	14	220	36	450	57	S.D. PSI
4.7	4.9	5.1	13.1	8.6	14.2	C.V. %
350	32	440	100	1,260	142	R PSI
2,600	279	4,520	416	5,760	501	4. $\bar{X}$ PSI
6	6	6	6	6	6	N
120	40	330	32	230	27	S.D. PSI
4.5	14.3	7.2	7.8	4.0	5.4	C.V. %
290	120	1,000	90	530	64	R PSI

112 DAY TESTING STATISTICAL ANALYSIS SUMMARY

2,000 PSI		3,000 PSI		4,000 PSI		BATCH
ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	ULTIMATE COMP. STRENGTH	MODULUS OF RUPTURE	
7,080	1,800	9,370	1,520	9,840	1,300	1. X PSI
6	6	6	6	6	6	N
210	260	500	170	510	145	S.D. PSI
3.0	14.3	5.4	11.3	5.2	11.1	C.V. %
550	610	1,340	460	1,260	420	R PSI
6,540	1,460	8,860	1,460	9,930	1,400	9. X PSI
6	3	5	5	6	6	N
260		490	110	420	74	S.D. PSI
3.9		5.5	7.4	4.2	5.3	C.V. %
600		1,240	230	1,000	190	R PSI
6,220	991	7,890	980	9,320	930	7. X PSI
6	6	6	6	4	6	N
280	110	570	110	320	80	S.D. PSI
4.4	11.6	7.2	11.0	3.5	8.6	C.V. %
650	350	1,530	240	960	220	R PSI
5,970	1,550	8,020	1,660	9,220	1,570	2. X PSI
6	6	6	6	6	5	N
520	170	210	130	290	100	S.D. PSI
8.8	11.0	2.6	7.6	3.2	6.5	C.V. %
1,350	530	610	330	680	260	R PSI
4,920	1,390	6,350	1,340	7,710	1,210	8. X PSI
6	5	6	6	6	6	N
240	73	310	56	320	120	S.D. PSI
4.8	5.2	4.9	4.2	4.1	10.3	C.V. %
520	200	790	170	840	380	R PSI
3,140	343	4,410	438	5,860	555	3. X PSI
6	5	6	5	6	6	N
130	50	340	37	420	55	S.D. PSI
4.1	14.5	7.6	8.4	7.2	9.9	C.V. %
300	135	890	90	1,190	160	R PSI
2,870	343	4,360	466	5,710	517	10. X PSI
6	6	6	4	5	6	N
260	38	320	21	450	36	S.D. PSI
9.0	11.0	7.4	4.7	7.9	6.9	C.V. %
700	95	820	49	1,030	85	R PSI
2,820	288	4,370	447	5,600	551	4. X PSI
6	6	6	6	6	6	N
200	43	175	48	310	35	S.D. PSI
7.0	15.0	4.0	10.8	5.5	6.4	C.V. %
490	100	400	120	710	100	R PSI

Table 4. While these averages have no statistical significance, they do indicate that the lowest consistency of results came respectively from Batch 10, the 2,000 psi mix, and the 4 month tests. They also indicate the surprising fact that the high strength specimens (test temperatures below freezing) showed generally more consistent results than their weaker counterparts.

6.2 CONTROL SPECIMENS

The results of tests on control specimens are included in the summary data sheets of Appendix B; summaries and comparisons with the standard cylinder tests (Batch 4) are shown in Table 5.

The predominantly low strengths of the control cylinder tests may be attributed mainly to the reduced strength of the second cement supply compared with the first, as shown in Table 1. Therefore, specimens cast using concrete made with the second cement and aggregate supplies (Batches 8, 9, 10) must be considered as basically of lower strength than those cast using the first supplies.

The compressive strength of the modified cubes was less than or equal to that of the standard cylinders.

TABLE 4

AVERAGE COEFFICIENTS OF VARIATION

Group		Average C.V.% Cylinders	Average C.V.% Beams
<u>Batches</u>	(All Strengths and Ages)		
1 (-30°F)		4.1	8.1
9 (-15°F)		4.8	8.2
7 Special		3.8	9.5
2 (+0°F)		3.7	7.3
8 (+15°F)		4.3	7.7
3 (+35°F)		5.4	9.0
10 (+50°F)		7.5	10.4
4 (+70°F)		5.3	8.4
<u>Strength</u>	(All Batches and Ages)		
2,000 psi Design		5.2	10.4
3,000 psi Design		4.5	7.5
4,000 psi Design		4.9	7.9
<u>Test Age</u>	(All Strengths and Batches)		
7 Days		4.5	8.6
28 Days		4.8	8.1
2 Months		4.5	8.4
4 Months		5.4	9.4

TABLE 5

SUMMARY OF CONTROL SPECIMEN TESTS

Test Age	Design Strength psi	Batch 4, Standard Cylinders	Modified Cube Tests	Control Cylinder Tests
7 Days	2,000	1,330	1,470	1,140
	3,000	2,320	2,260	1,980
	4,000	3,170	3,420	3,090
28 Days	2,000	2,480	2,450	2,310
	3,000	4,110	3,680	3,130
	4,000	5,370	4,560	5,130
2 Months	2,000	2,660	2,560	2,660
	3,000	4,520	3,810	3,980
	4,000	5,760	4,780	5,430
4 Months	2,000	2,820	2,840	2,790
	3,000	4,370	4,400	4,500
	4,000	5,600	5,560	5,340

6.3. CHANGE IN COMPRESSIVE STRENGTH WITH TEMPERATURE

The average relative compressive strengths at various test temperatures together with a strength range indicating the relative reliability of each average are plotted for particular ages in Figs. 7A to 7D. Values were obtained from Tables 2A to 2D. The plotted band consists of the average strength plus or minus the standard deviation times a probability factor which is a function of the number of specimen test values used to compute the average. The factor giving a probability of 0.90 was chosen for the purposes of this report; numerical values were obtained from Troxell and Davis (10), Fig.17-3. Literally translated, there would be 9 chances out of 10 that another specimen, made of the same components and tested at a particular age and temperature in the same manner as used in this investigation, would have a strength within the plotted band. Therefore, the smaller the band for a particular magnitude of compressive strength, the more reliable the average compressive strength. The standard deviation, and consequently the band width, would be expected to be larger for larger magnitudes of compressive strength.

The fact that the compressive strength of concrete is higher at test temperatures below the freezing point of

FIG. 7 A

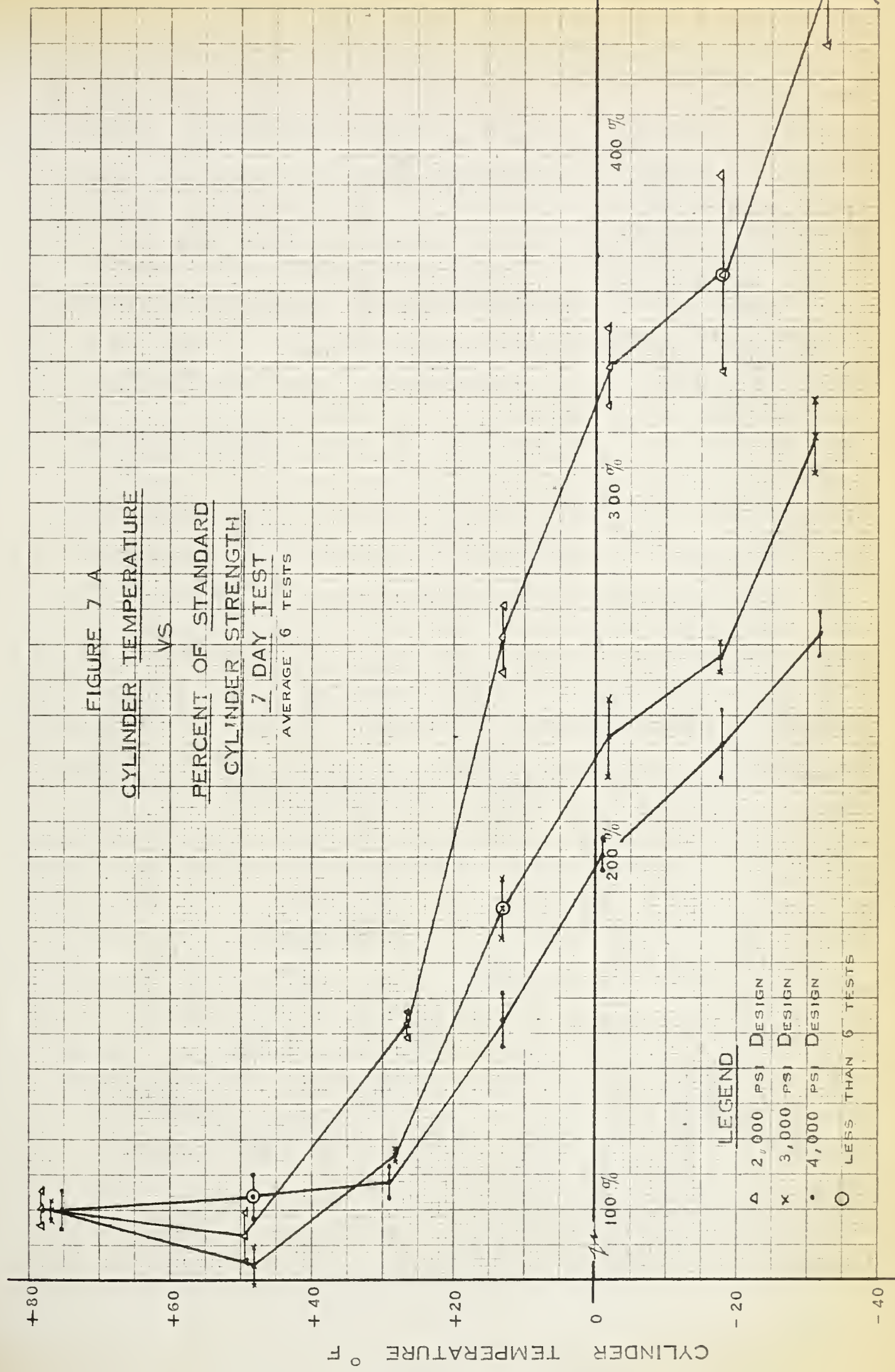


FIG. 7 B

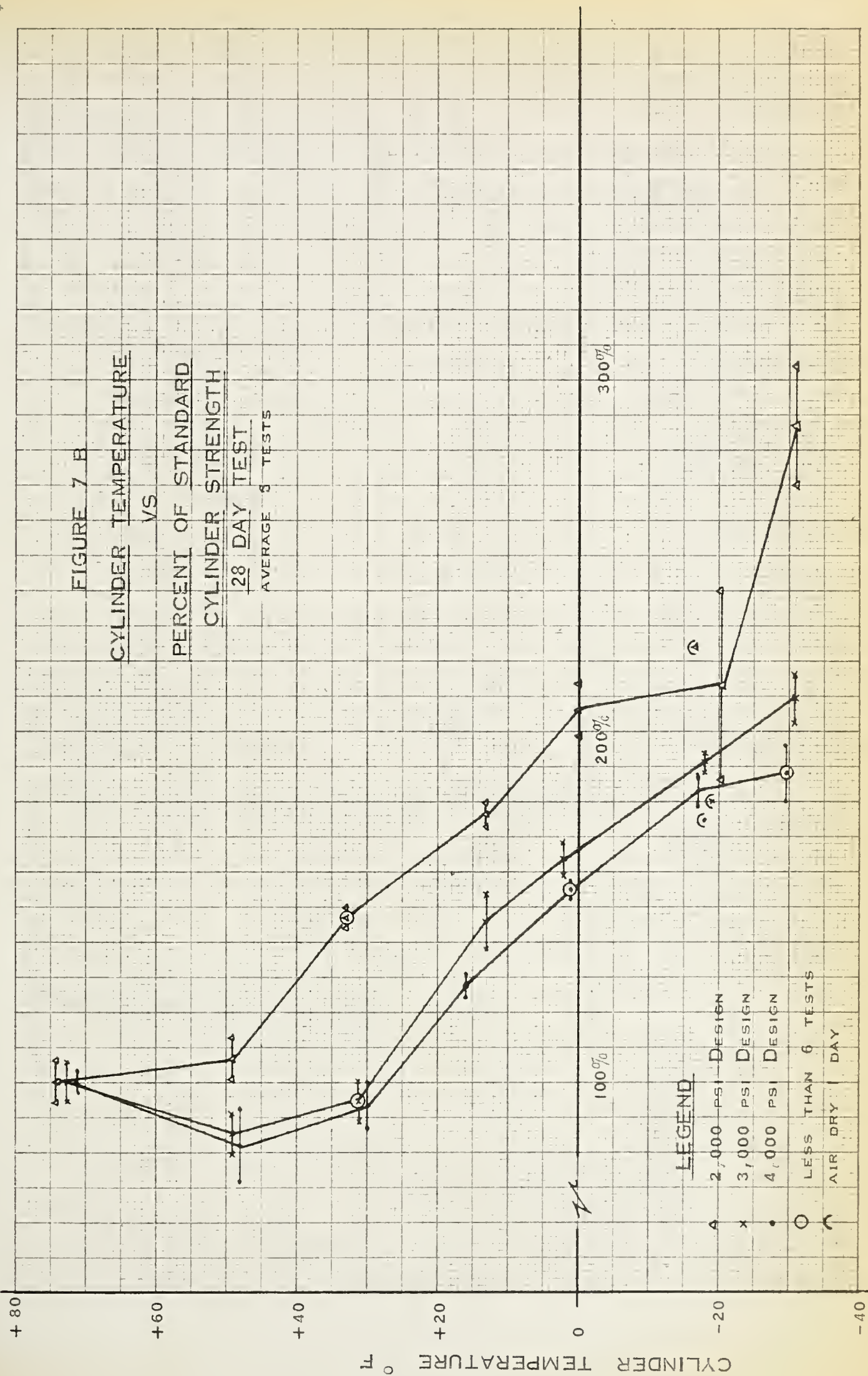


FIG. 7 C

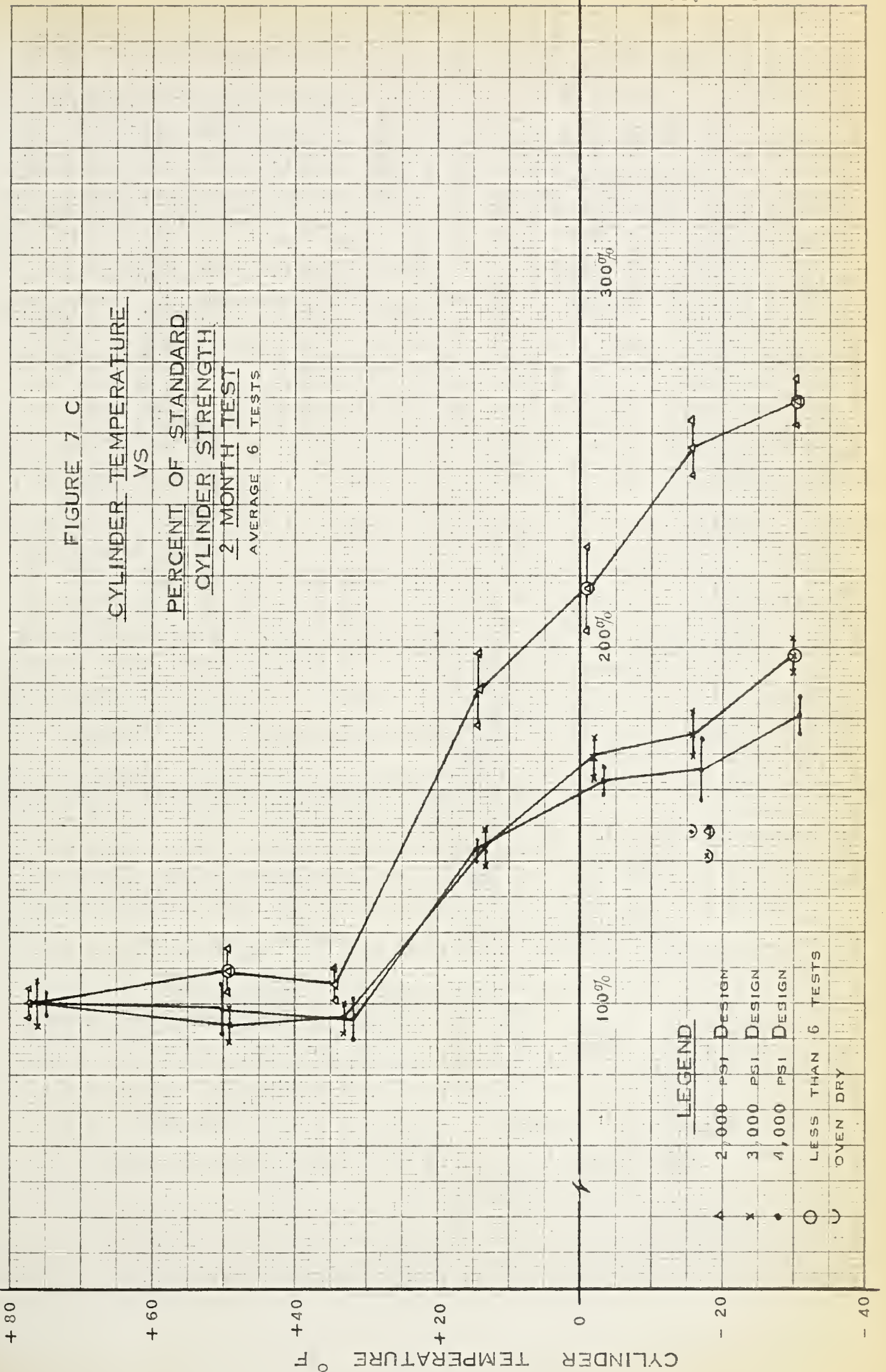
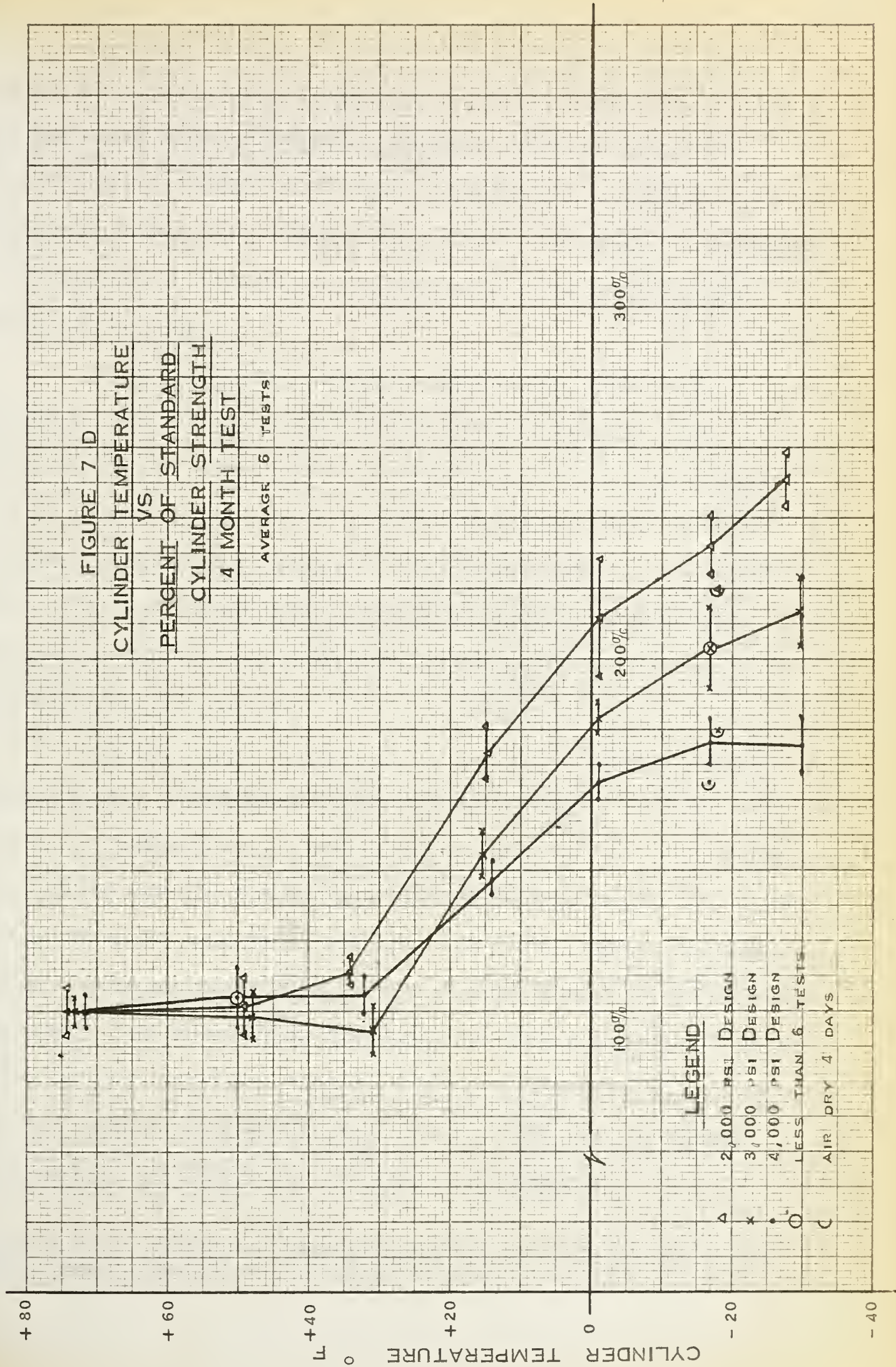


FIG. 7 D



water* is conclusively indicated in Figs. 7A to 7D. The maximum percentage strength increase obtained was 350% (7 day test on 2,000 psi design cylinders at -33° F.) All cylinders tested at temperatures below freezing had strengths substantially above the strengths of the corresponding standard cylinders.

No significant strength change was noted for specimens tested at temperatures above freezing. The majority of the compressive strengths of specimens tested at $+50^{\circ}$ F (Batch 10) were actually less than those of the standard specimens. However, this discrepancy is probably due to the difference in concrete strengths of the first and second cement and aggregate supplies as explained in Section 6.2.

Examination of Figs. 7A to 7D shows that an abrupt change in the temperature-compressive strength relationship occurs at temperatures immediately below $+32^{\circ}$ F. The magnitude of the abrupt change is relatively higher for the lower design strength specimens and for the 7 day tests. The percentage strength gain increased for decreasing freezing temperatures; for decreasing temperatures below about $+20^{\circ}$ F an approximately constant rate of strength increase of one percent per degree Fahrenheit was obtained for all specimens irrespective of their age or design strength.

*Reference to freezing temperatures in subsequent sections will signify temperatures below $+32^{\circ}$ F.

The percentage strength increase in compressive strength was significantly higher for the 7 day than the 28 day tests but was approximately constant for the older test ages. The increase was also higher for the lower design strengths, the percentage difference between the 2,000 and 3,000 psi design specimens being greater than that between the 3,000 and 4,000 psi design specimens.

Specimens of Batch 7 were subjected to various degrees of drying and then tested at temperatures of -15°F to determine the effect of drying on the strength. The amount of drying is indicated in Tables 2B to 2D. Test results are shown on Figs. 7B to 7D. In all cases, drying resulted in a reduced percentage strength increase, the amount of reduction depending upon the amount of drying (i.e. the reduction was proportional to the decrease in moisture content).

6.4. CHANGE IN FLEXURAL STRENGTH WITH TEMPERATURE

The average values of the modulus of rupture at various test temperatures are plotted in Figs. 8A to 8D. Values were obtained from Tables 2A to 2D. The method of presentation is identical to that used in Section 6.3. The test results from the flexural tests are similar to

FIGURE 8 A
BEAM TEMPERATURE
VS
PERCENT OF STANDARD
BEAM STRENGTH
7 DAY TEST
AVERAGE 6 TESTS

LEGEND

- △ 2,000 PSI DESIGN
- x 3,000 PSI DESIGN
- 4,000 PSI DESIGN
- LESS THAN 6 TESTS

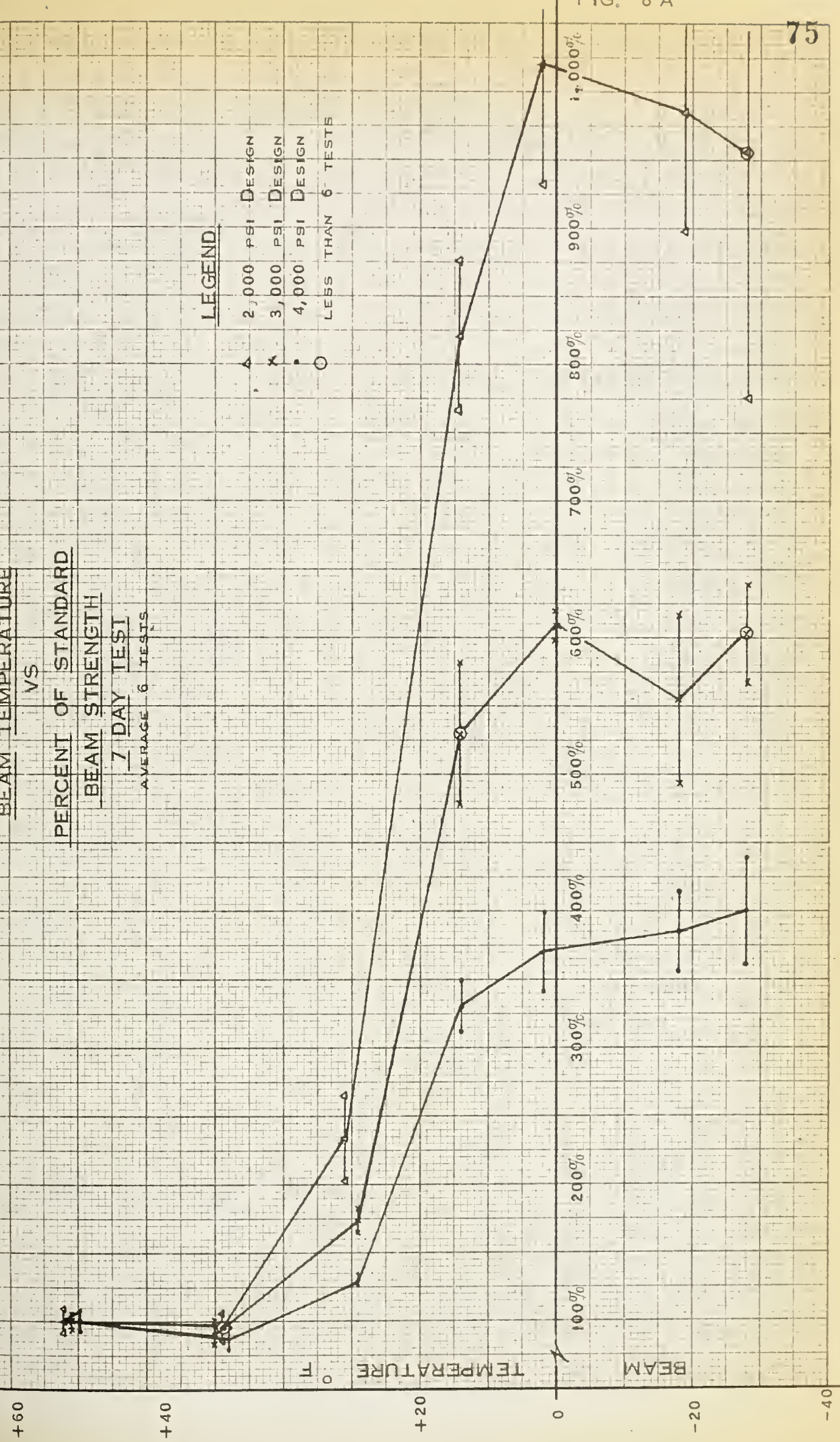


FIG. 8 B

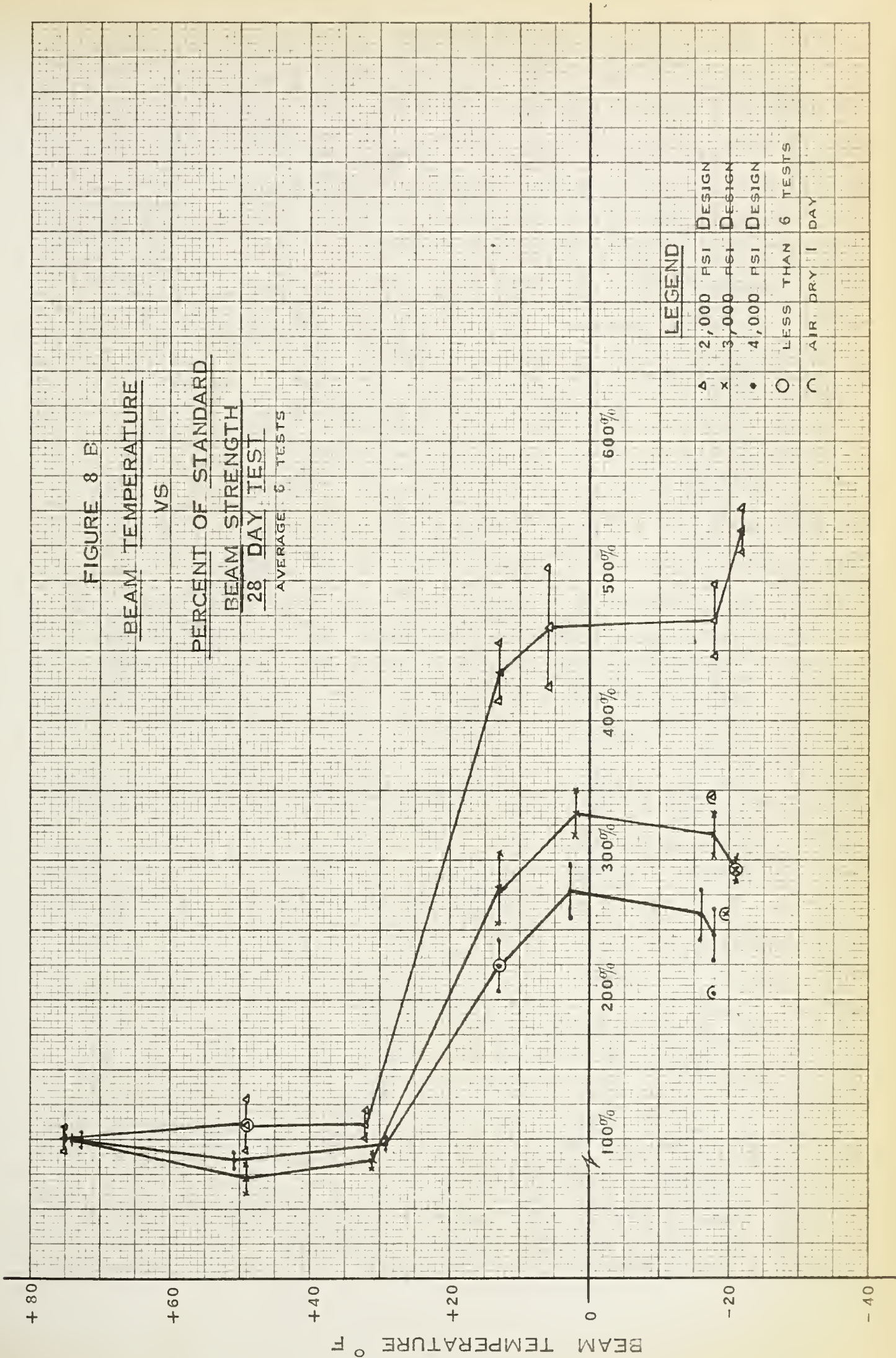


FIG. 8 C

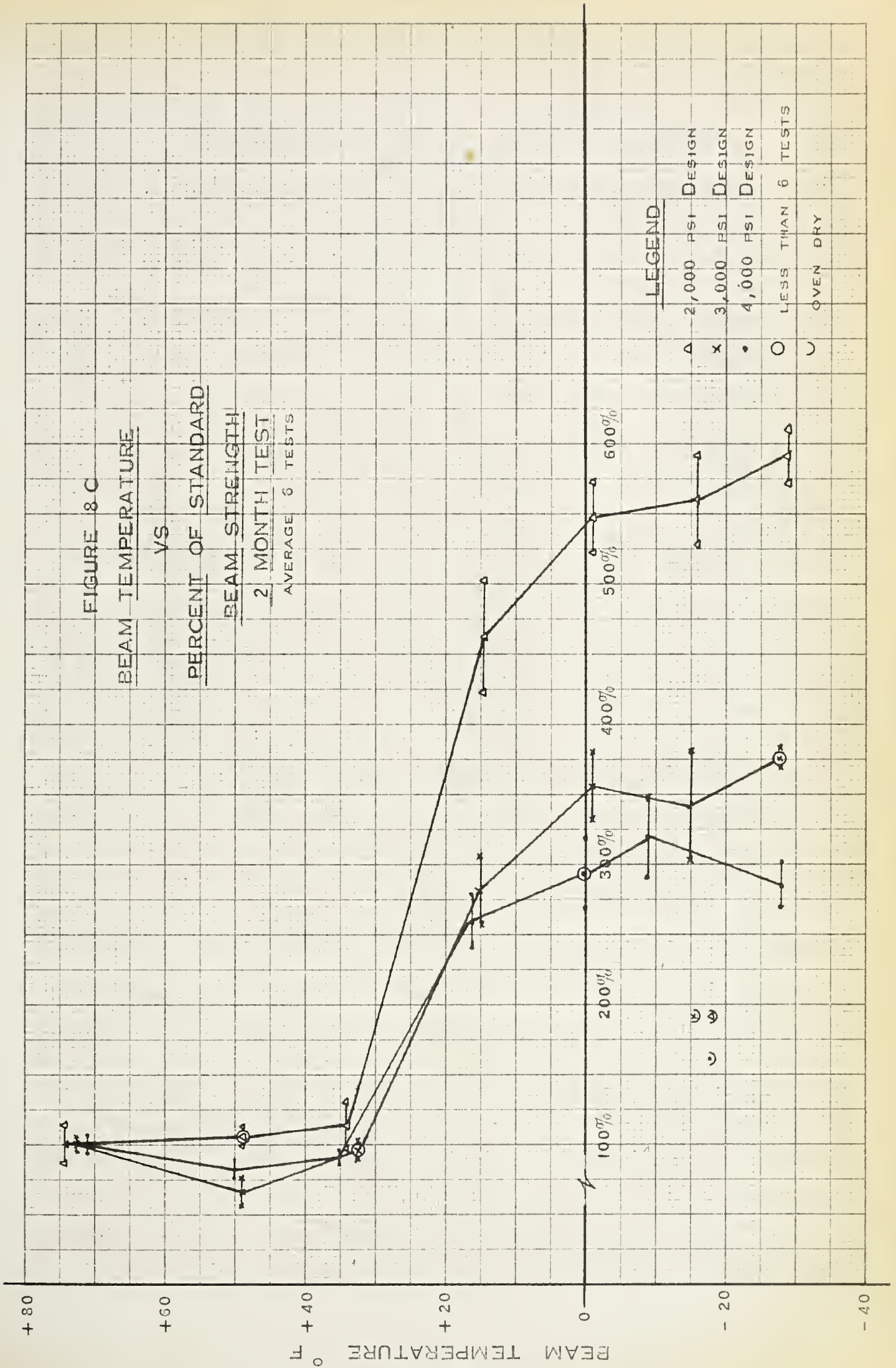
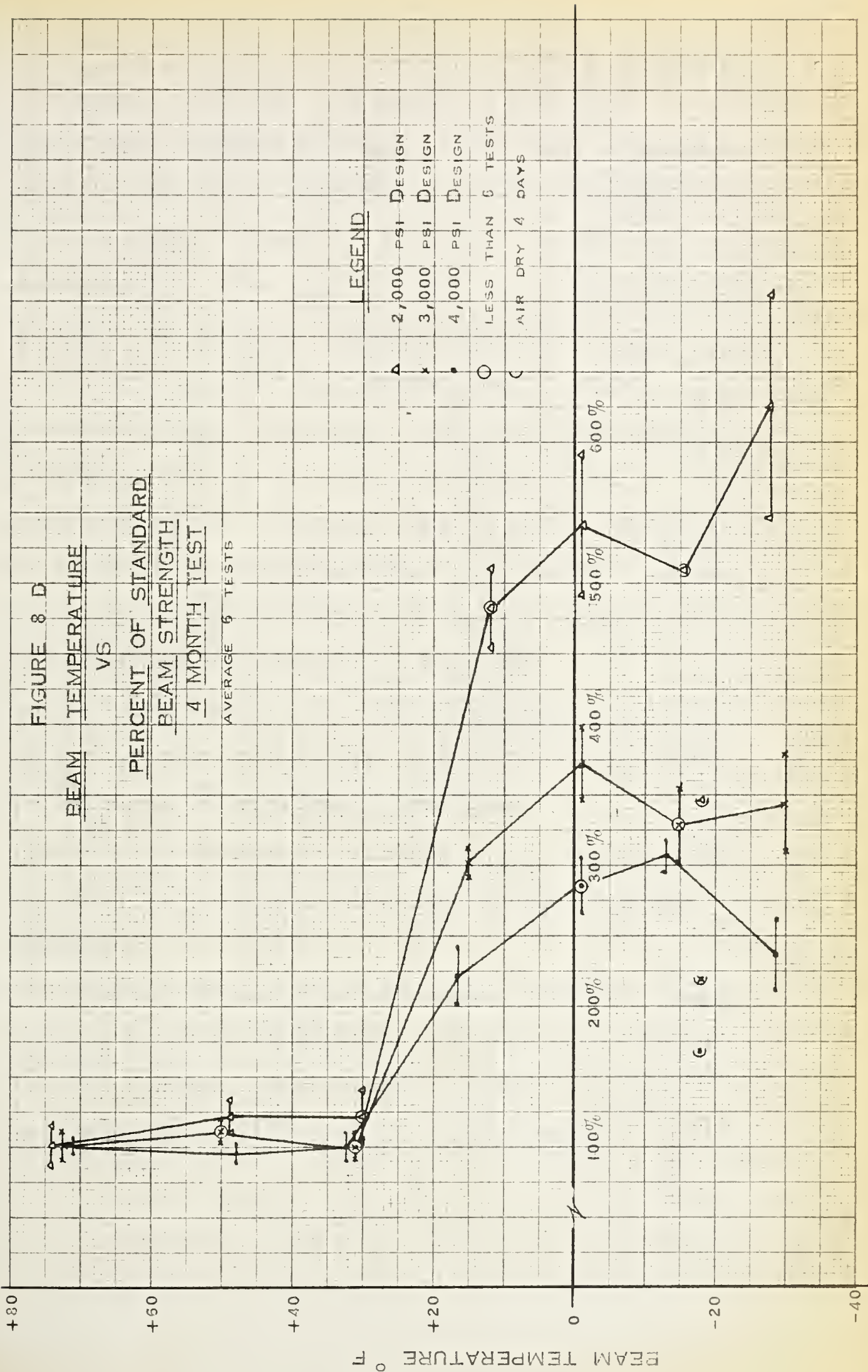


FIG. 8 D



those for the compression tests except in order of magnitude of strength increase. Therefore, in summary:

- i) Significant strength increases were noted only for specimens tested at temperatures below freezing. The percentage increase in flexural strength was approximately twice that obtained for compressive strength, the maximum increase being about 850% (7 day test on 2,000 psi design beam at -29°F .
- ii) An abrupt change in the test temperature -flexural strength relationship occurs at temperatures immediately below freezing. The results of tests at the lower freezing temperatures are somewhat erratic and no consistent relationship between strength increase and temperature was obtained.
- iii) The percentage gain in flexural strength is approximately constant for all ages except the 7 day tests for which it is considerably greater.
- iv) Percentage increases in strength were inversely proportional to the design strengths of the flexural specimens.
- v) Test results for the dried specimens (Batch 7) shown in Figs. 8B to 8D indicate a reduction in percentage strength increase with reduced moisture content, particularly for the 2,000 psi design beams.

6.5. AGE-STRENGTH RELATIONSHIPS

The age-compressive strength and age-flexural strength relationships are shown in Figs. 9A to 9E, a separate Figure being used for each test temperature. Values were obtained from Tables 2A to 2D.

For test temperatures above freezing, the age-strength relationship for both compressive and flexural strength was of the general form with the rate of increase in strength decreasing with age. Results of some of the flexural tests are erratic. Values of the 7 day flexural testing of Batch 3 and the 2 month flexural testing of Batch 10 are omitted, the former because the test was conducted at a below freezing temperature as intended in the initial testing program, and the latter because of failure of the frost room controls during specimen conditioning.

For test-temperatures below freezing, unusual age-strength relationships were obtained. The flexural strength was approximately constant at all test ages. The compressive strength showed a gradual increase in strength when tested at ages up to about 2 months, after which, the strength remained constant or decreased slightly.

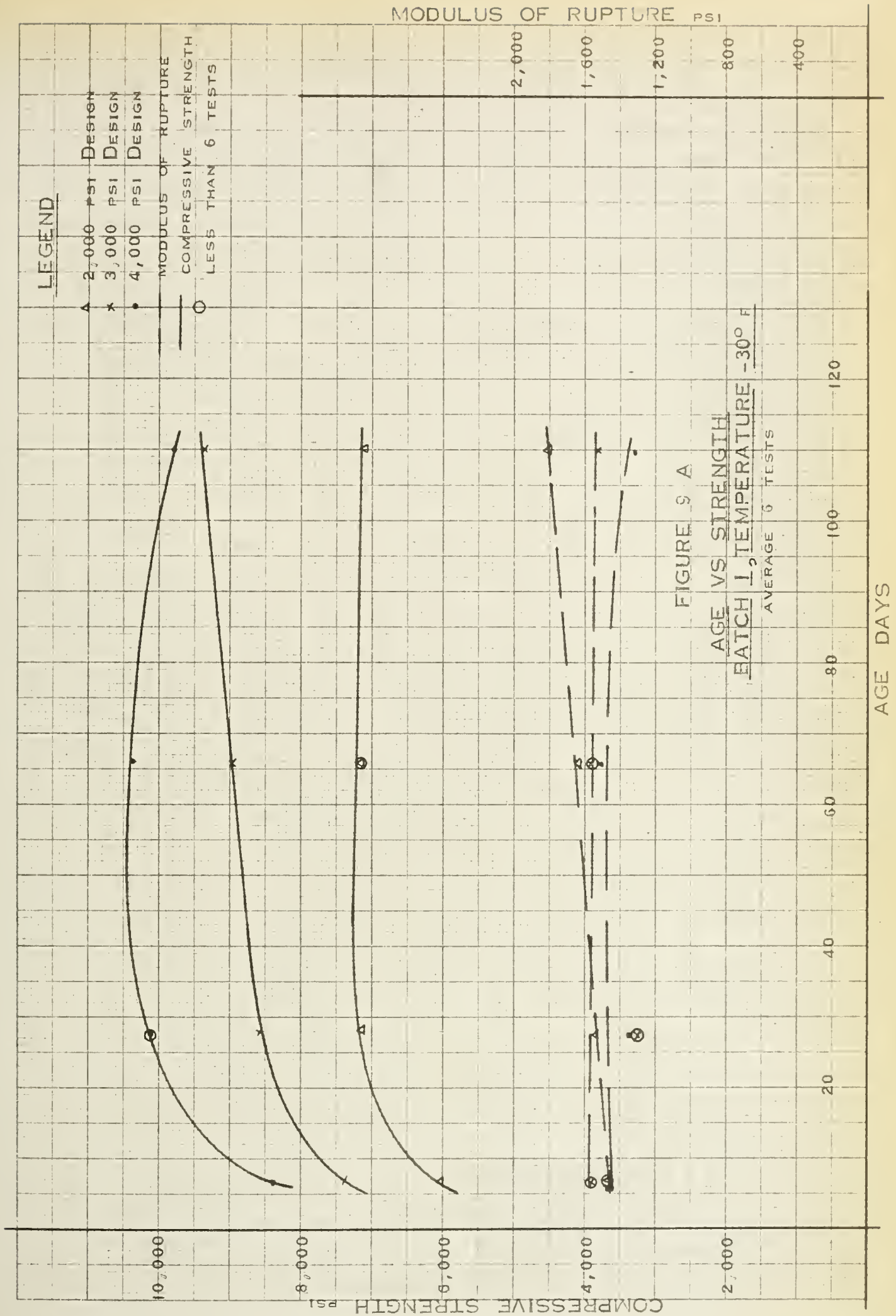


FIG. 9 B

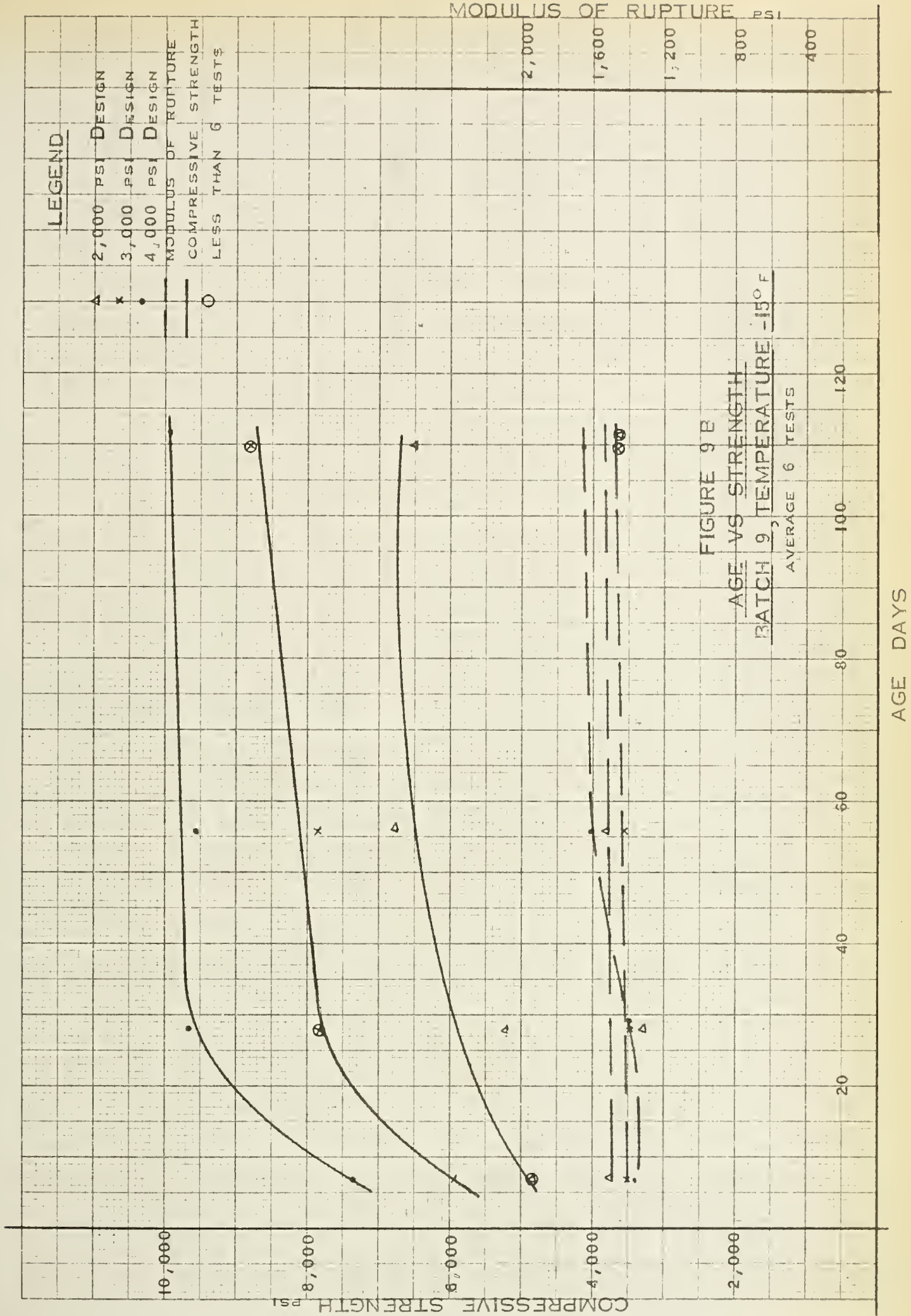


FIG. 9 C

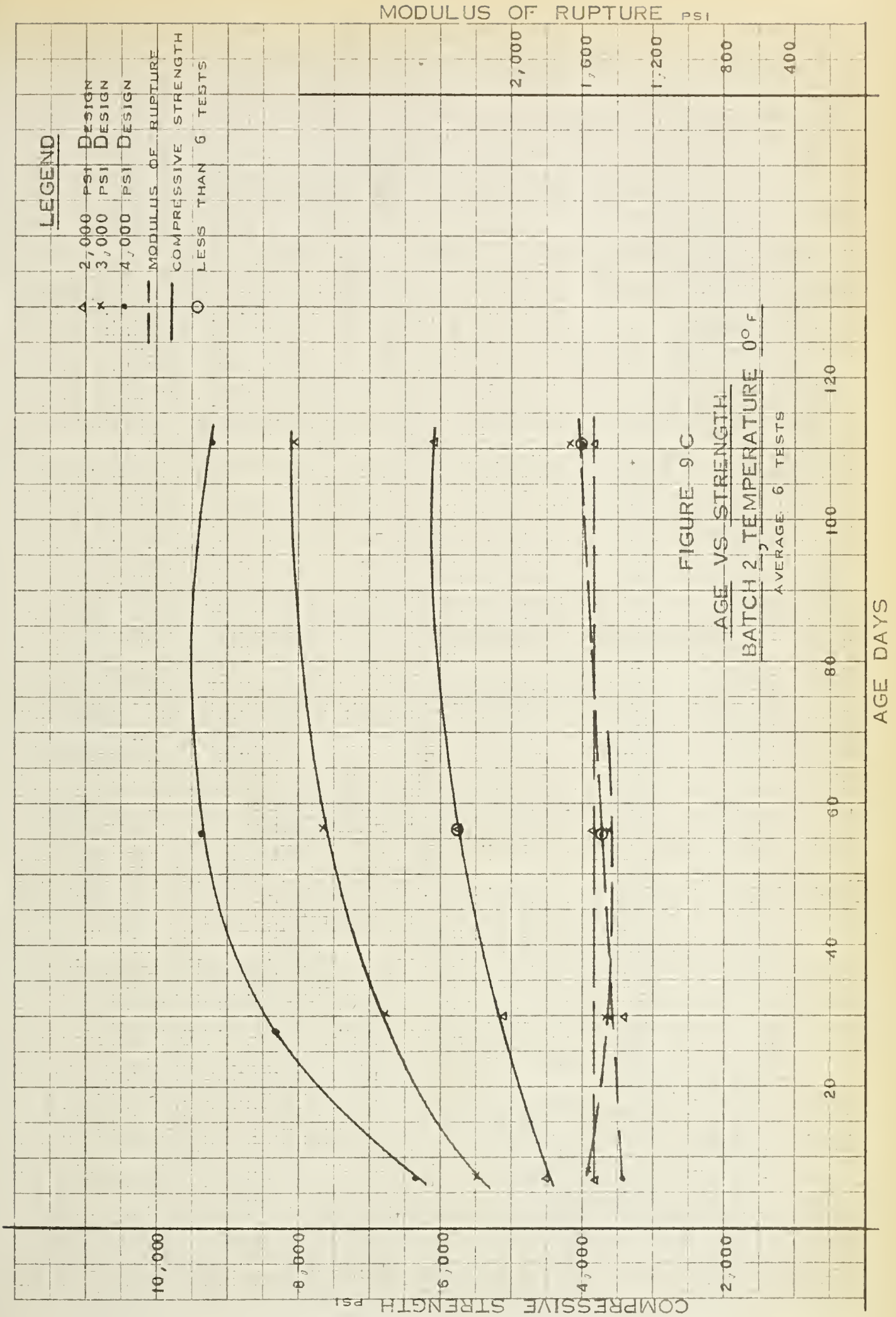


FIG. 9 D

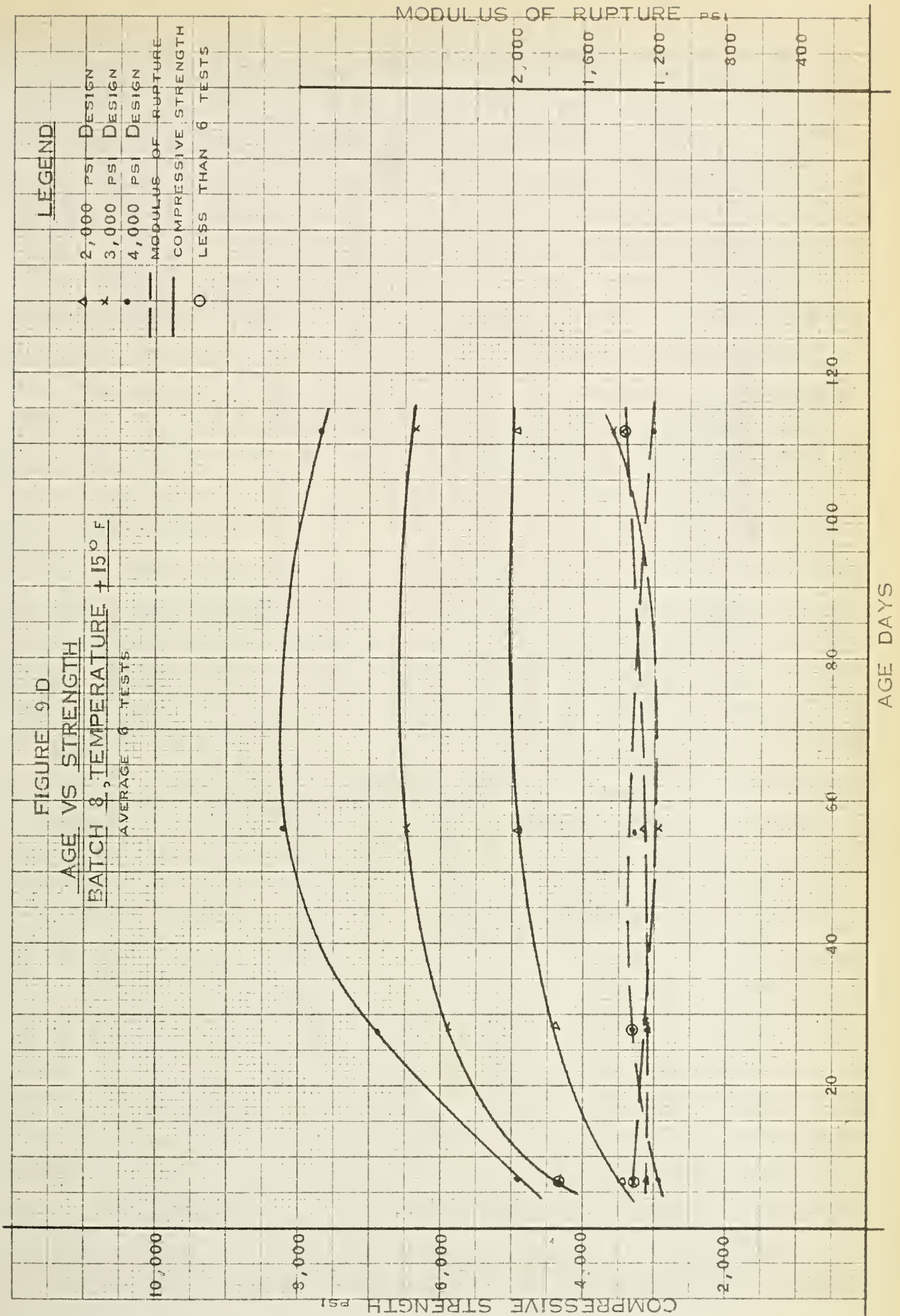
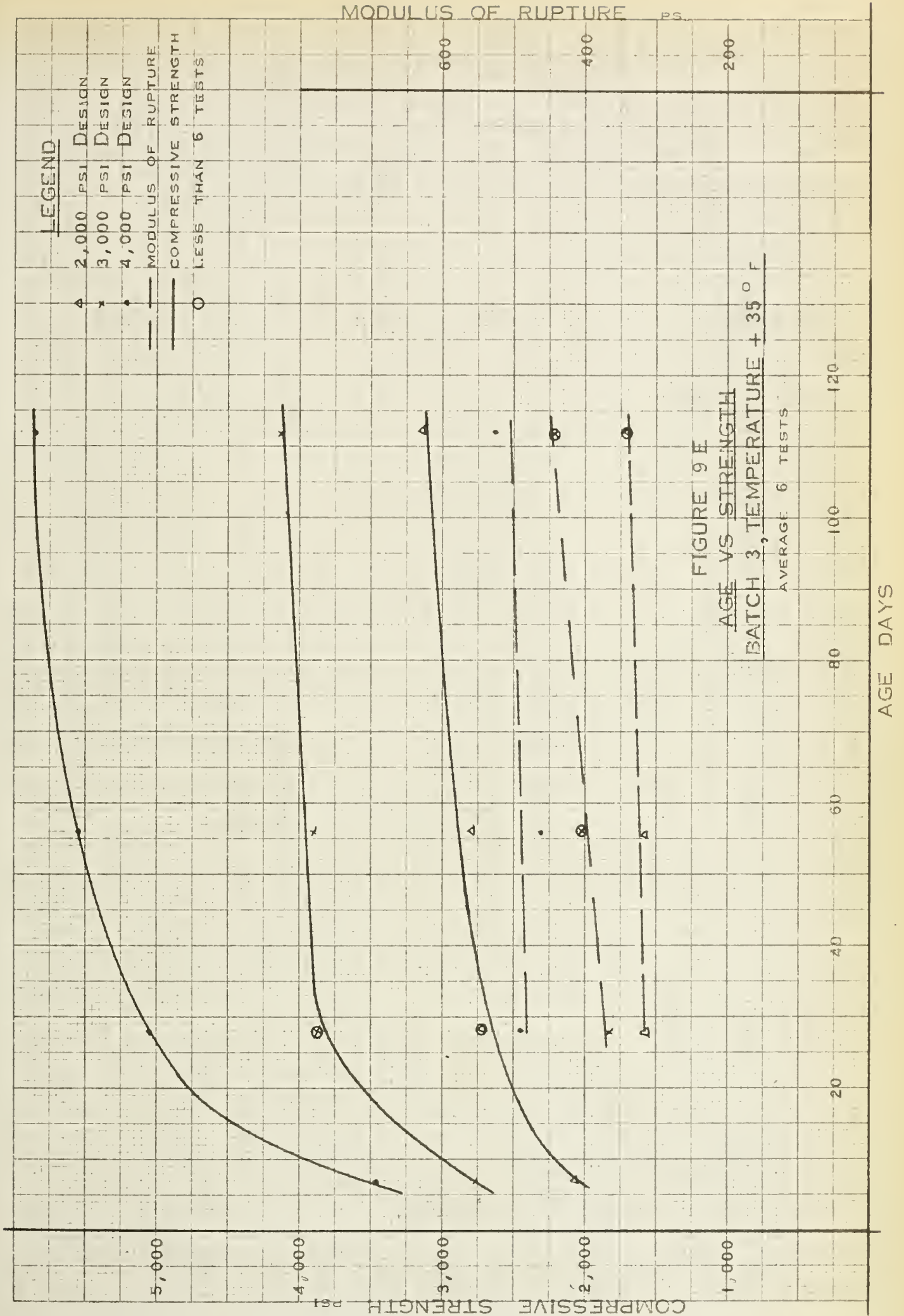
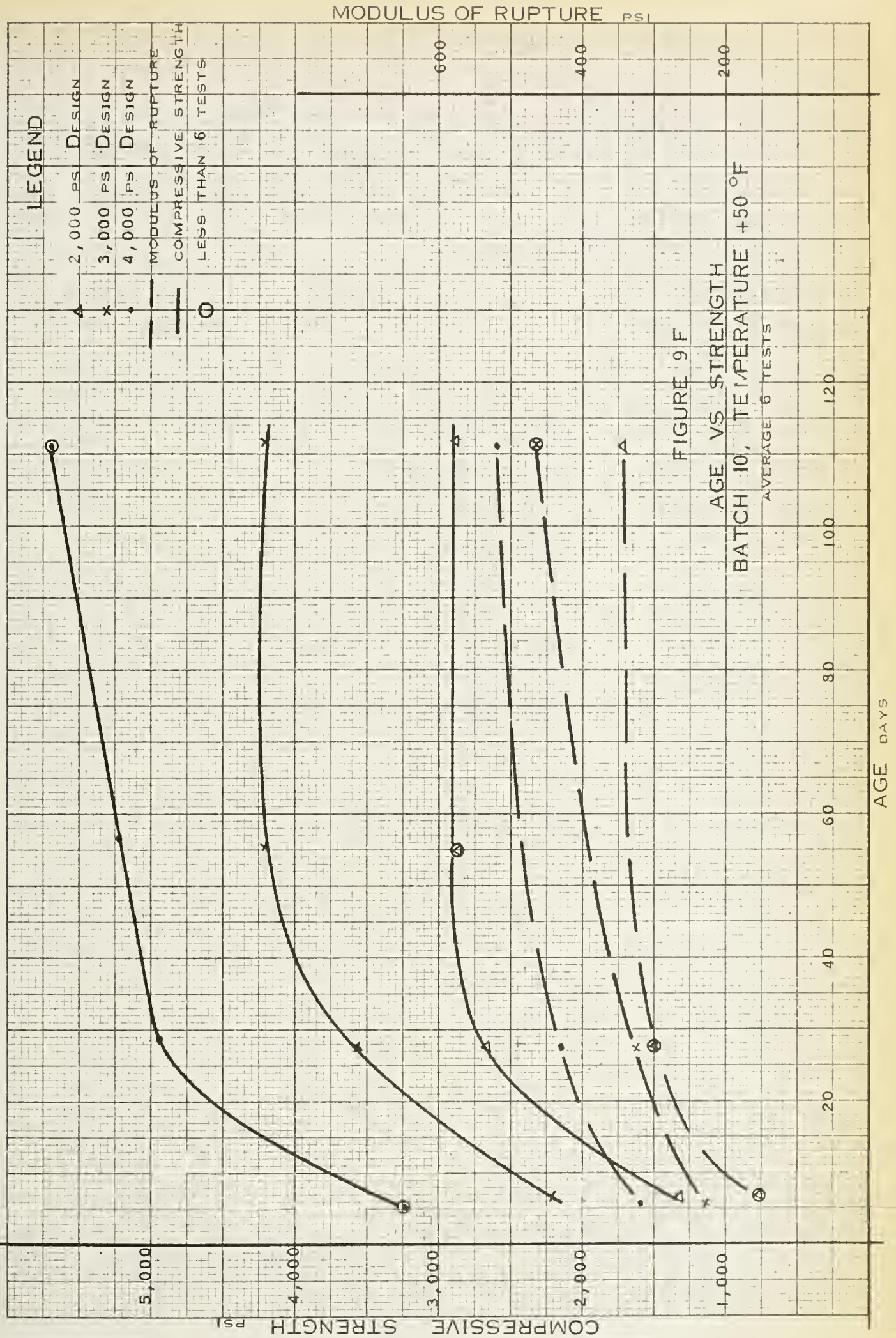
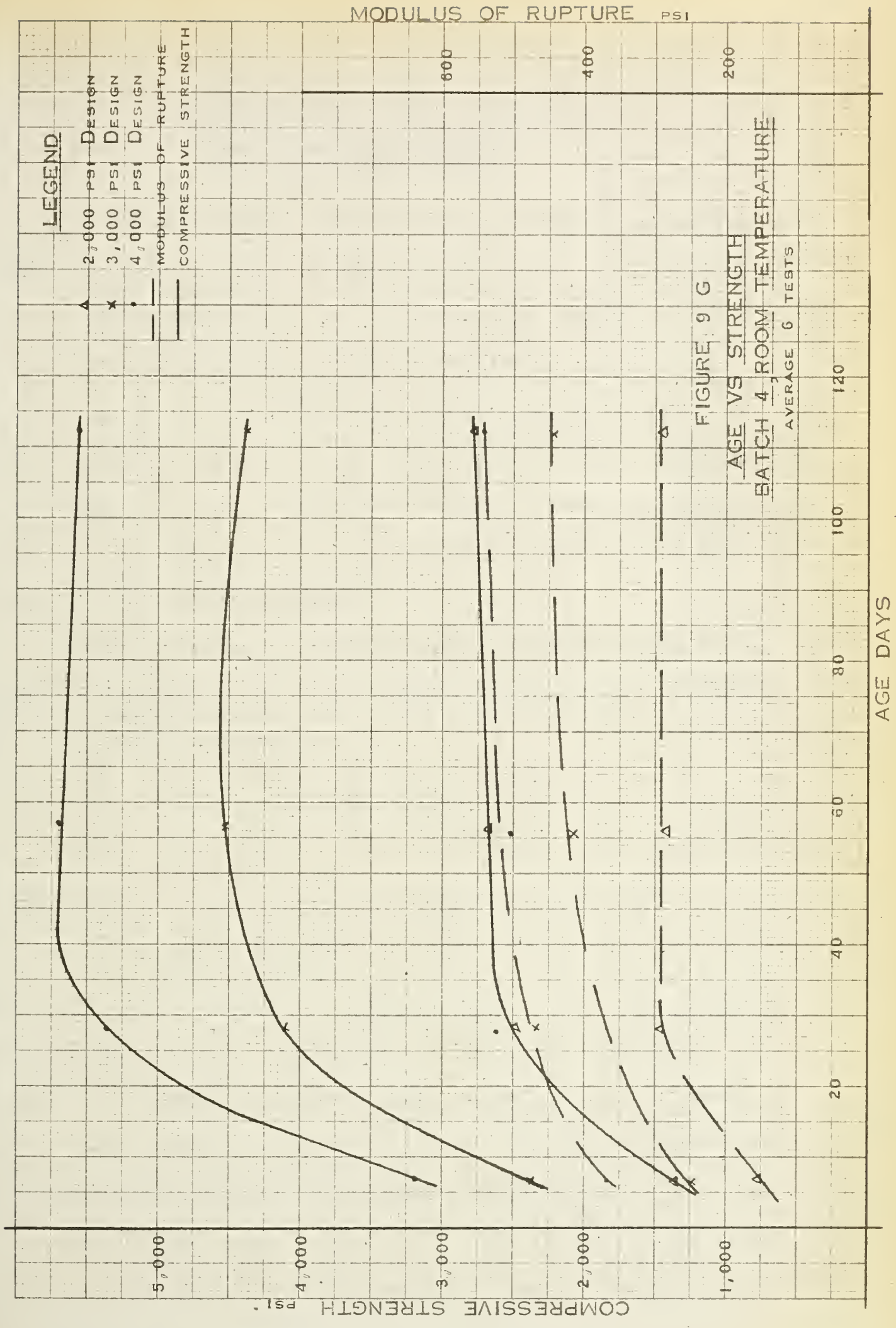


FIG. 9 E







6.6. RELATIONSHIP BETWEEN COMPRESSIVE AND FLEXURAL STRENGTH

The relationship between flexural and compressive strength for the average values of all tests is shown in Fig. 10. The grouping of test results for tests at temperatures above and below freezing is clearly indicated. The upper group is a result of the percentage increase in flexural strength being about twice that for the compressive strength for test temperatures below freezing. Generally, strengths from Batches 8, 9 and 10 were lower than comparable strengths of the other batches.

Fig. 11 shows the relationship between flexural and compressive strength for test temperatures above freezing only. The results indicate:

$$f_r = 0.13 f_c \text{ at } f_c = 1,000 \text{ psi}$$

$$f_r = 0.09 f_c \text{ at } f_c = 6,000 \text{ psi}$$

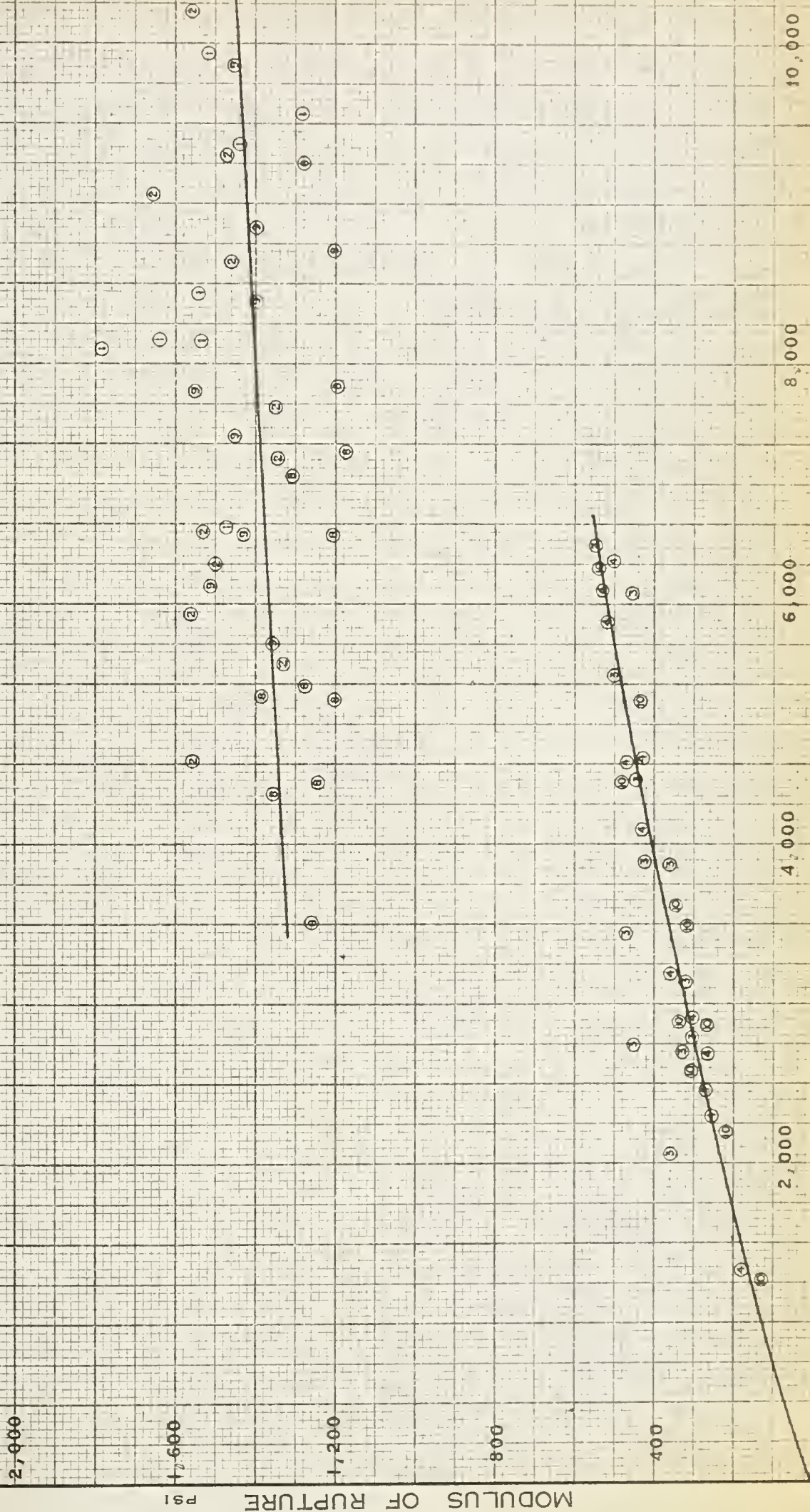
The approximate equation of the best fit curve is:

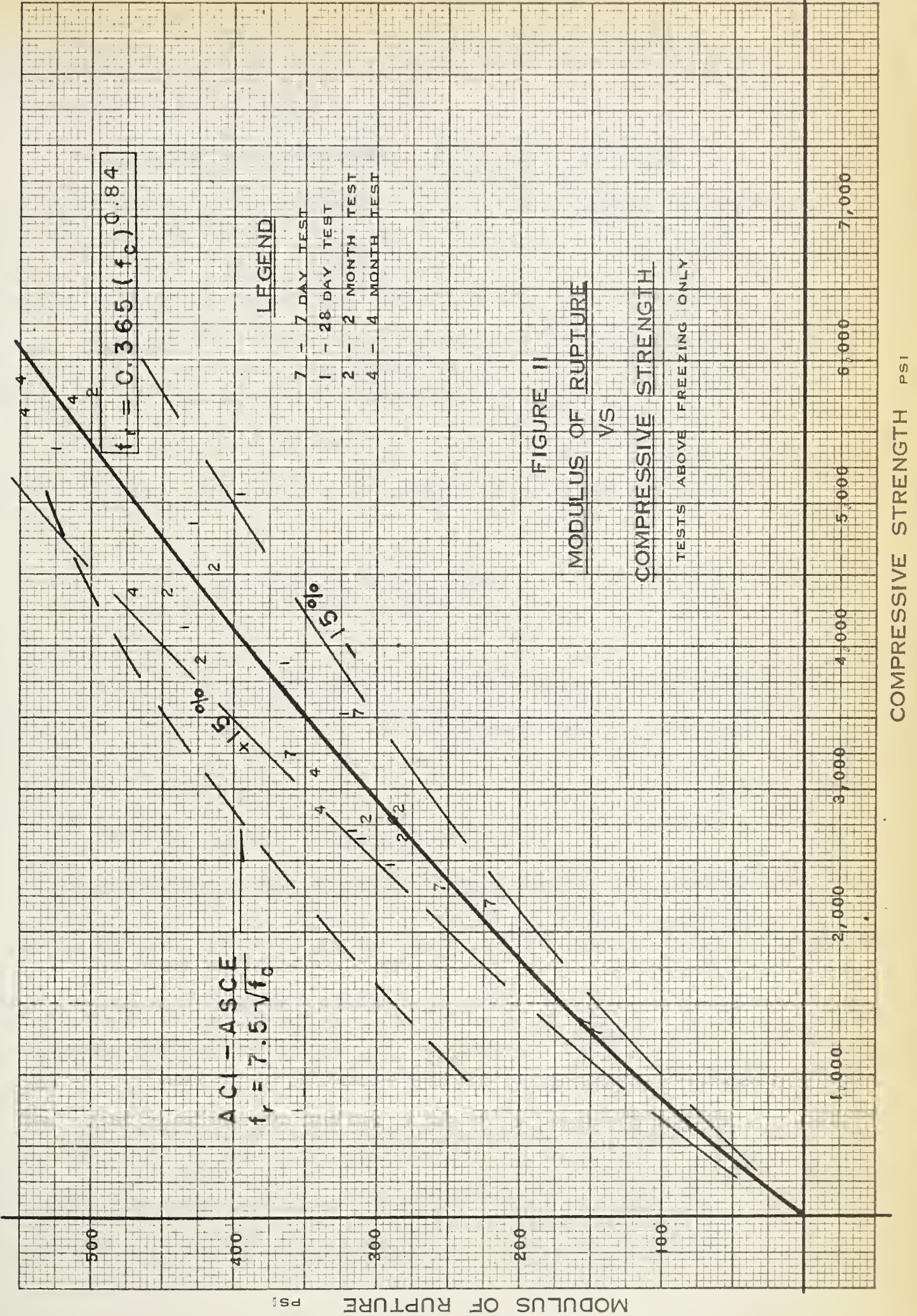
$$f_r = 0.365 (f_c)^{0.84}$$

where f_r is the modulus of rupture and f_c the compressive strength both in psi. With the exception of one test result, all values are contained in a band equal to the best fit curve plus or minus 15 percent. For the results of the tests at temperatures above freezing, the

FIGURE 10
MODULUS OF RUPTURE
VS
COMPRESSIVE STRENGTH

ALL TEST TEMPERATURES
NUMBERS INDICATE BATCH NUMBERS





flexural-compressive strength relationship was independent of the test age or temperature.

For comparison purposes, the A.C.I.-A.S.C.E. Joint Committee #323 equation for the relationship between compressive and flexural strength is plotted in Fig. 11. A direct comparison cannot be made as the A.C.I.-A.S.C.E. equation is based on f'_c , the standard 28 day compressive strength, while the equation derived from the test results of this investigation is based on f_c , the ultimate compressive strength irrespective of age or test conditions.

6.7. MODULUS OF ELASTICITY

The stress-strain curves for all ages and batches are shown in Appendix C. For this report, the following definitions were used:

- i) Secant Modulus of Elasticity (E_s) -
the ratio of the stress at 45 percent of ultimate compressive stress to the corresponding strain.
- ii) Chord Modulus of Elasticity (E_c) -
the ratio of the stress increment between 25 and 45 percent of ultimate compressive stress to the corresponding strain increment.

A graphical representation of the above definitions is shown at the beginning of Appendix C. The stress-strain

curves used in this report were obtained by an unusual method. Basically, strain readings were taken at pre-determined stress increments for each of the six cylinders of a test group. For a particular stress, the strain readings of all six cylinders were averaged and this average value of strain was used for plotting the stress-strain curves. A check of the values of the modulus of elasticity of individual cylinder stress-strain curves indicated that this method gave representative results. Additional explanation is given at the beginning of Appendix C.

The values of the percentage increase in chord and secant moduli of elasticity for various test temperatures are presented in Tables 2A to 2D but are not shown graphically as the modulus of elasticity - test temperature relationship would be similar in form although of a lower magnitude to that shown in Figs. 7A to 7D. Examination of Tables 2A to 2D indicates that Batch 2 had relatively high values of both the chord and the secant moduli.

The relationships between the secant and chord moduli of elasticity and the compressive strength are shown in Figs. 12 and 13 respectively. The expressions for the best fit curves are:

$$\begin{aligned} E_s &= 0.060 \times 10^6 \sqrt{f_c} - 130 f_c \\ E_c &= 0.050 \times 10^6 \sqrt{f_c} - 150 f_c \end{aligned}$$

where f_c is the ultimate compressive strength in psi.

FIGURE 12

SECANT MODULUS

VS

COMPRESSIVE STRENGTH

ALL TESTS

6.0

5.0

4.0

3.0

2.0

1.0

PSI

$\times 10^6$

SECANT MODULUS

$$E_s = 0.060 \times 10^6 \sqrt{f_c} - 130 f_c$$

+15%

-15%

NOTE - EACH POINT REFERS TO
BATCH NUMBER AND IS
AVERAGE OF 6 TESTS.

1,000

2,000

3,000

4,000

5,000

6,000

7,000

8,000

9,000

COMPRESSIVE STRENGTH PSI

FIGURE 13

CHORD MODULUS

VS

COMPRESSIVE STRENGTH

ALL TESTS

CHORD MODULUS $\times 10^6$ PSI

$$E_c = 0.50 \times 10^6 \sqrt{f_c} - 150 f_c$$

+15%

-15%

NOTE -- EACH POINT REFERS TO
BATCH NUMBER AND IS AVERAGE
OF 6 TESTS.

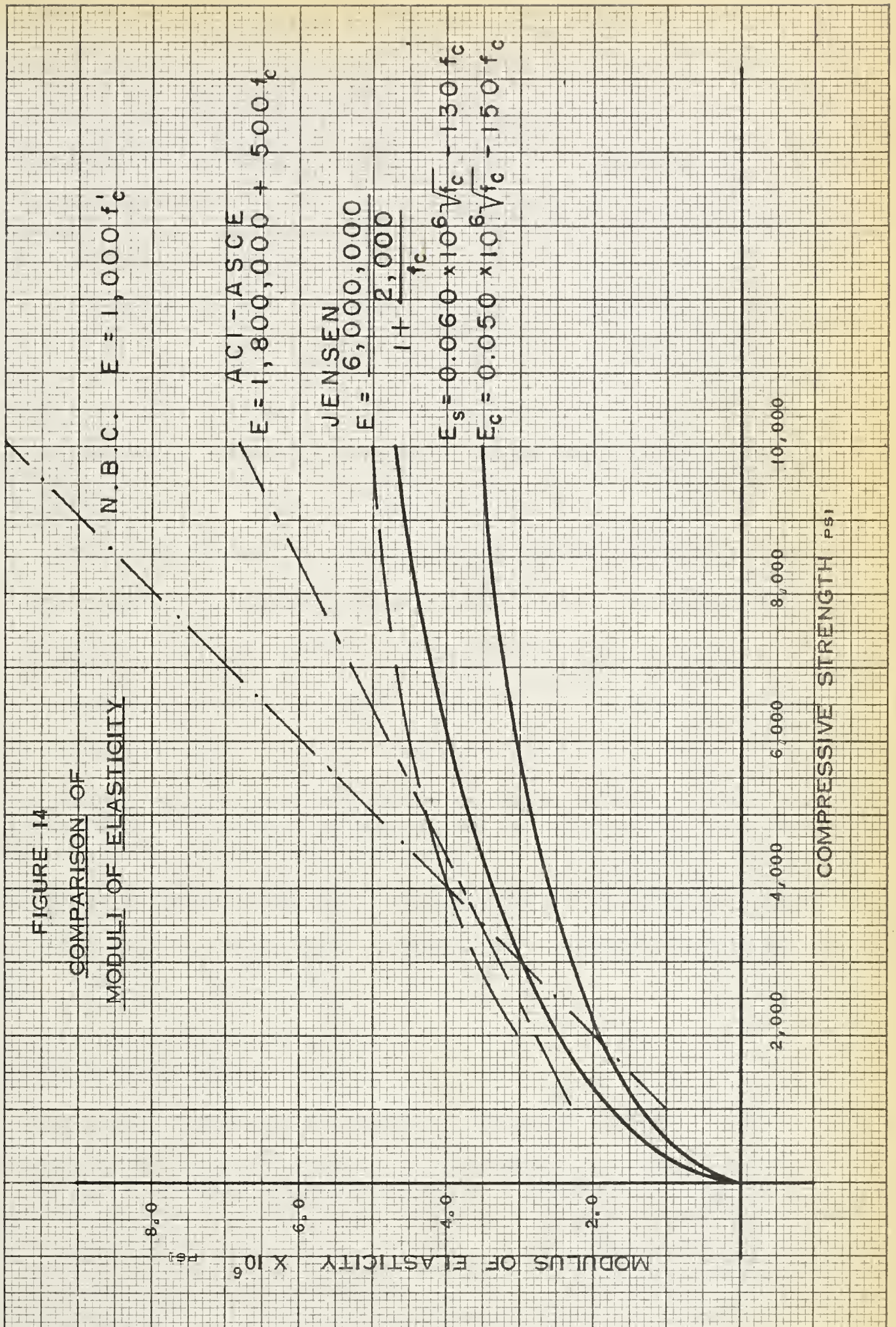
1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000 9,000

COMPRESSIVE STRENGTH PSI

The majority of the test results are contained in a band equal to the foregoing equations plus or minus 15 percent. Both best fit curves are of the usual shape with the modulus of elasticity decreasing with increasing values of the compressive strength. Figs. 12 and 13 indicate that temperature, as such, does not effect the modulus of elasticity because the batch numbers representing various test temperatures did not show any tendency to group.

The chord modulus is not a common expression for the modulus of elasticity of concrete. It was selected for this investigation to avoid the inclusion of any initial curvature error (see Sect. 5.2.3.). However, the results show similar consistency for both chord and secant moduli, indicating that the initial curvature error was low. In general, numerical values of the chord modulus were about 80% of those of the secant modulus for a particular compressive strength.

Comparison of test results with published relationships between the modulus of elasticity and compressive strength are shown in Fig. 14 (see Sect. 3.5.). The equation proposed by Jensen and that of the A.C.I.-A.S.C.E. Joint Committee #323 are both based on the initial tangent modulus.



6.8. SPECIMEN FAILURES

6.8.1. CYLINDER FAILURES

Cylinders tested at temperatures above freezing generally failed in the theoretical form indicated in Sect. 3.7. Those of low strength failed by crushing of the central portion of the cylinder without the formation of any "cones". Some of those of higher strength failed by diagonal splitting through the coarse aggregate particles. Typical failures are shown in Plate 4A and 4B.

Cylinders tested at temperatures below freezing failed by diagonal or longitudinal splitting. The majority of the failures were of the latter form in which a cone formed at one end of the cylinder causing splitting into two, three or four pieces. A check indicated that in almost all cases the cone formed at the cylinder end in contact with the upper loading head (the upper loading head is ball-jointed and stationary) regardless of the orientation of the cylinder with respect to its direction of molding. Typical failures are shown in Plate 5A and 5B.

6.8.2. BEAM FAILURES

All specimens failed between the load points. The direction of the failure planes were within 15 degrees



Plate 4 A Formation of Theoretical
Cone



Plate 4 B Crushing Failure of
Low Strength Concrete

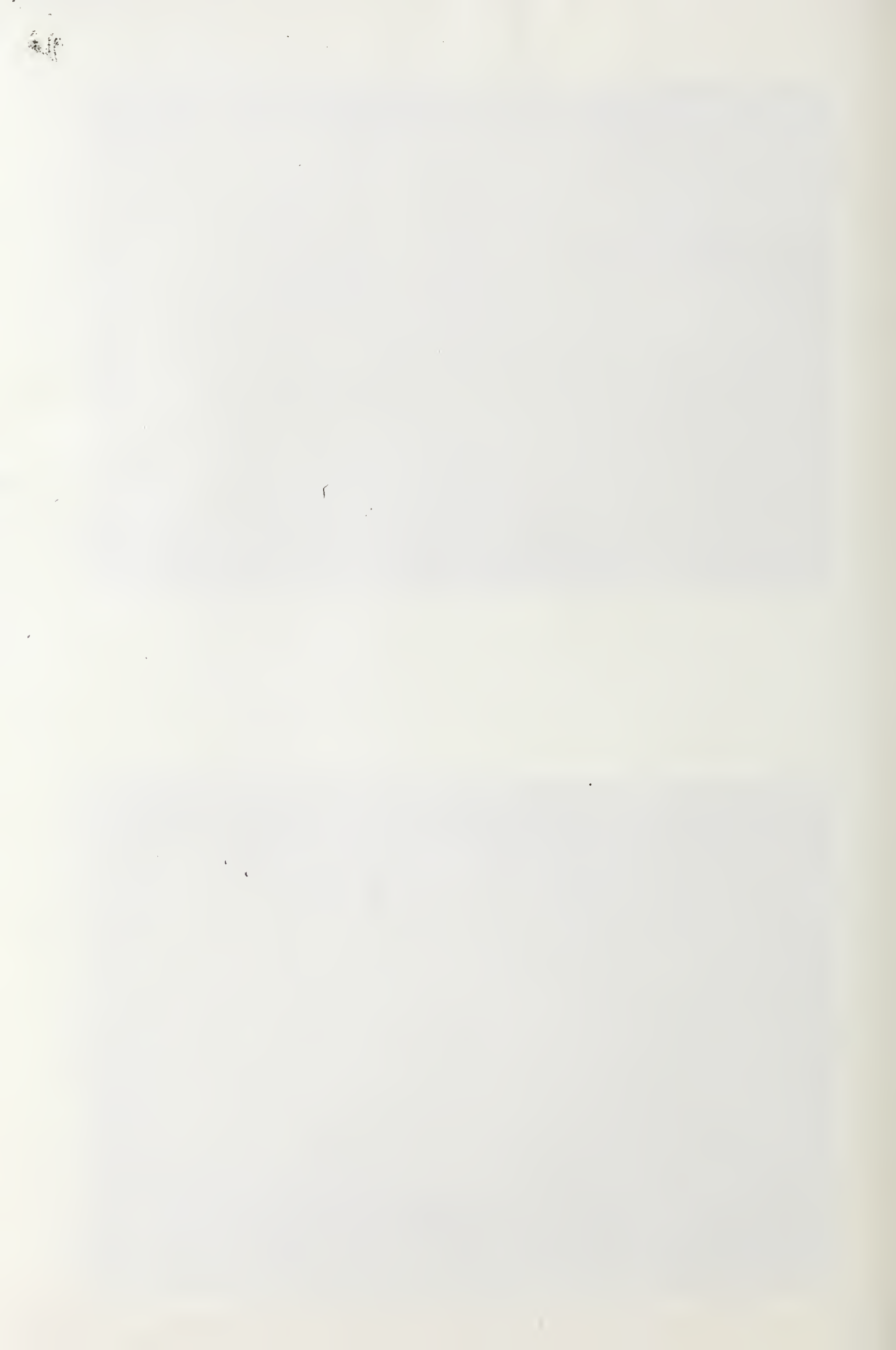




Plate 5 A
Longitudinal Splitting Failure
With Cone



Plate 5 B Four Piece Longitudinal Split Failure

of being parallel to the direction of loading, which is in agreement with the theory of Sect. 3.7.

Examination of the failure cross sections showed that some aggregate particles were split in beams with moduli of rupture as low as 300 psi. Beams tested at temperatures below freezing had 80 percent or more of their coarse aggregate split through the section of failure.

6.8.3. PRESENCE OF ICE PARTICLES

Arbitrarily selected portions of failed beams and cylinders tested at temperatures below freezing were examined under a fifty power microscope. No ice was visible in the air pores. A limited number of ice particles were visible in the paste structure.

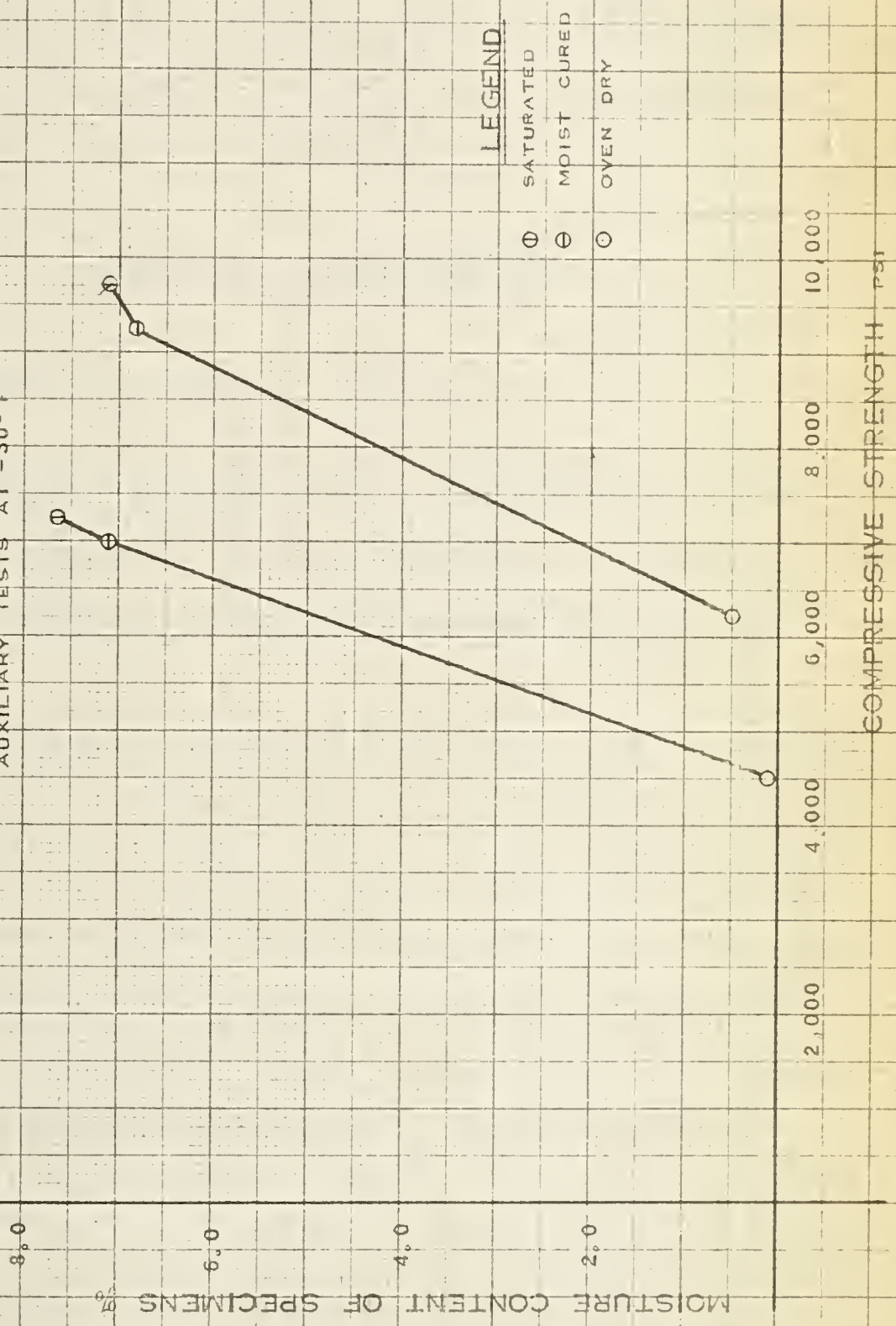
6.9. AUXILIARY TEST RESULTS

The "no cement" specimens had an average compressive strength of 1,730 psi for the 2,000 psi design proportions and 1,570 psi for the 4,000 psi proportions.

The results of the tests on the cylinders conditioned for 48 hours by soaking in water, moist curing, or oven drying prior to testing at -30°F are shown in Fig. 15. Each value is for 1 cylinder only. The significance of the moisture content on the strength increase of specimens tested at temperatures below freezing is clearly indicated.

FIG. 15

FIGURE 15
EFFECT OF MOISTURE CONTENT
ON COMPRESSIVE STRENGTH
AUXILIARY TESTS AT -30° F



CHAPTER 7

D I S C U S S I O N

The test results will be discussed with particular reference to their significance and to their comparison with results by other investigators.

7.1. DISCUSSION OF TEST RESULTS

7.1.1. DISCUSSION OF PRIMARY RESULTS

The primary purpose of this investigation was to determine the effect of low test temperature on the compressive and flexural strength and modulus of elasticity of concrete.

It was shown in Sect. 6.2. and 6.3. that cylinders and beams tested at temperatures in the $+70^{\circ}\text{F}$ to $+32^{\circ}\text{F}$ range had approximately the same strength. These results do not agree with those obtained by Hoff and Bauer (see Sect. 1.2.) whose tests showed small strength increases for specimens tested in this temperature range. The results of similar tests by Saemann and Washa (see Figs. 1 and 2) are too

erratic to be conclusive. This investigator believes that Hoff and Bauer erroneously attribute the strength gain to a temperature effect rather than a strength gain due to drying during conditioning.

For cylinders and beams tested at temperatures below the freezing point of water, the test results presented in Sect. 6.2 and 6.3. show phenomenal compressive and flexural strength gains over comparable strengths of specimens tested at standard temperatures. The percentage gain in flexural strength was found to be about twice that of the compressive strength for specimens made from the same concrete. For both flexural and compressive strength the percentage increases were found to be:

- i) considerably higher for the 2,000 psi design mix than for the 3,000 and 4,000 psi design mixes,
- ii) slightly higher at lower freezing temperatures,
- iii) considerably higher for the 7 day tests than for the later test ages,
- iv) considerably reduced by drying of the test specimens prior to conditioning at below freezing temperatures.

With regard to iv) above, it should be noted that drying of specimens prior to testing at normal temperatures should

produce a strength increase rather than a decrease. It is felt that the above points are not significant in themselves but are all related to the fact that the percentage increase in strength is a function of the amount of moisture in the concrete. The results of tests by Huyghe, Bauer, and Saemann and Washa, summarized in Sect. 1.2., agree with the findings of this investigation in that all investigators obtained considerable strength increases in specimens tested at temperatures below freezing. However, with the exception of Huyghe's results, the percentage strength increases in the forementioned reports are of lower magnitude than those of this investigation. The reason for the difference is not evident. Huyghe's results also show the percentage gain in flexural strength to be about twice that for compressive strength.

The modulus of elasticity was not affected by the range of test temperatures considered in this investigation; the influence of temperature was only insofar as it affected the strength. This was shown in Figs. 12 and 13. Since the modulus of elasticity increases at a decreasing rate with increasing compressive strength, a percentage increase in compressive strength would be expected to produce a correspondingly lower percentage increase in the modulus of elasticity. This is consistent with the results shown in Tables 2A and 2D in that lower percentage increases were obtained in the chord and secant moduli than in the compressive

strength. Huyghe compared the sonic modulus of elasticity of medium and high strength concrete tested at -40° F and $+68^{\circ}$ F. He obtained increases in the sonic modulus at the low temperature equal to 23% for the medium strength and 12% for the high strength concrete. For comparative concrete strengths, increases of about 30% for the former and 10% for the latter are obtained from Figs. 12 and 13 of this investigation.

7.1.2. DISCUSSION OF SECONDARY RESULTS

Test results related to the primary purpose of this investigation are discussed in Sect. 7.1.1. In addition to these, incidental results were obtained from the data and are discussed briefly below.

The compressive strength of the modified cubes was less than or equal to that of standard cylinders from the same batch (see Table 5). On the basis of length to diameter ratio, the modified cubes would be expected to have about 15% higher strengths than comparable cylinders. The discrepancy may be due in part to reduced strength of the cubes caused by testing in a saturated condition.

With regard to the relationship between compressive and flexural strength shown in Figure 11

(test temperatures above freezing only), the results of this investigation showed the flexural strength to be a lower percentage of the compressive strength than that indicated by published results noted in Sect. 3.6.

Published results also indicated that relatively high values of flexural strength would be obtained using beams of small cross section similar to those of this investigation. In particular the test results do not agree with the A.C.I.-A.S.C.E. equation as shown in Fig. 11. However, a direct comparison cannot be made because the values plotted from this testing program are not determined from specimens tested under standard conditions.

Comparison of the relationship between the modulus of elasticity and the compressive strength as determined in this investigation and as given in published results is shown in Fig. 14. Although, again, direct comparison cannot be made, the results of this investigation agree, in form, with those obtained by Jensen. Since Jensen's equation is for the initial tangent modulus, he obtained higher magnitudes of the modulus of elasticity for a particular compressive strength than those obtained by the chord and secant moduli methods in this investigation.

7.2. SIGNIFICANCE OF TEST RESULTS

The author believes that the purpose of this investigation was fulfilled and that the results presented herein are valid for the range of test conditions considered. The results are of major significance for test temperatures below freezing only.

In consideration of test results at below freezing temperatures, it must be emphasized that the testing program consisted primarily of standard, moist cured concrete beams and cylinders conditioned for a short time at a selected temperature below the standard test temperature. Therefore, the specimens contained a relatively high percentage of moisture when tested. Since, as indicated by the test results, large gains in strength were coincident with high moisture contents, application of the results of this investigation to field conditions would depend on the determination of the amount of moisture in the field concrete. The amount of moisture would be a function of the relative humidity of the environment, the advancement of hydration and the original water-cement ratio of the concrete. The author feels that properly cured, dry, mature (an age in excess of perhaps one year) concrete subjected to, and tested at, below freezing temperatures would show very little strength increase over the same concrete tested at normal temperatures.

With reference to the problem in the continuously reinforced concrete test road noted in Sect. 1.1., since considerable amounts of environmental moisture would be available to pavements, the test results of this investigation indicate that the tensile strength of the concrete during the winter months would be increased. The increase could conceivably be of sufficient magnitude to prevent cracking of the concrete, causing excessive straining of the pavement reinforcement at preformed cracks.

The consistency of the primary test results of this investigation have been evaluated by a statistical analysis. Comparison of the computed values of the coefficient of variation against the suggested standards for concrete compression test control suggested by A.C.I. 214 (see beginning of Appendix B) indicates that the compression tests would be classified as "fair". If a similar classification is applicable to flexural test results, then those of this investigation would be classified as "poor". Other investigators reviewed in Sect. 3.6. have also obtained relatively high coefficients of variation for flexural tests, particularly those using beams of small cross section.

Some inconsistency of test results may be attributed to changes in specimen strengths caused by differences between the first and second supplies of cement and aggregate. It should be noted that the results of this investigation

are obtained by comparing test values of supposedly identical specimens subjected to various test temperatures.

Actually, the specimens compared were from separate mixes of varying slumps (see Table 1) and varying strengths (see results of control specimen tests, Table 5).

In summary, the two fundamental questions which arise from a consideration of the strength of concrete at below freezing temperatures are "... does the strength of concrete change?" and, if so, "why?" In answer to the first question this investigation indicates that concrete can exhibit many times its design strength when cooled to temperatures below the freezing point of water, the magnitude of strength increase being to some degree dependent upon the moisture content of the concrete. Unfortunately, this author is unable to present a satisfactory answer to the second question.

CHAPTER 8

C O N C L U S I O N S

The conclusions from this investigation were considered in terms of primary conclusions related to the purpose of the investigation and secondary conclusions incidental to the testing program.

8.1. PRIMARY CONCLUSIONS

1. The compressive and flexural strength of standard cured concrete specimens subjected, prior to testing, to temperatures below the freezing point of water is much in excess of that of equivalent specimens tested under standard conditions. Compressive strengths of cylinders tested at below freezing temperatures in this investigation were from a minimum of 150% to a maximum of 450% of equivalent standard test cylinders; the corresponding range for flexural strengths of beams was from 280% to 950%.

2. The increase in concrete strength at test temperatures below freezing appears to be a function of the moisture content of the specimens, being higher for higher moisture contents. Consistent with this conclusion, the test results reported herein showed;

- i) higher percentage strength increases for specimens molded of concrete of high water-cement

ratio,

ii) higher percentage strength increases for early test ages,

iii) lower percentage strength increases for specimens dried before testing.

3. The compressive and flexural strength of standard cured concrete specimens subjected, prior to testing, to temperatures in the range between the standard test temperature and the freezing point of water are approximately the same as equivalent specimens tested under standard conditions.

4. For temperatures between $+70^{\circ}\text{F}$ and -30°F , the modulus of elasticity of concrete is not dependent upon the concrete temperature except insofar as the temperature affects the compressive strength of the concrete.

8.2. SECONDARY CONCLUSIONS

1. The flexural strength of standard cured concrete, tested at temperatures below freezing, is approximately a constant with respect to age.

2. The compressive strength of standard cured concrete, tested at temperatures below freezing, increases gradually for test ages up to about 2 months, then remains constant or decreases slightly for older test ages.

3. For the test conditions reported herein, the relationship between compressive and flexural strength of concrete tested at temperatures above freezing can be approximated by;

$$f_r = 0.365 (f_c)^{0.84}$$

4. Computation of the modulus of elasticity of concrete by the chord method gives values about 20% lower than by the secant method. The uniformity of results is similar for both methods.

5. The modulus of elasticity increases at a decreasing rate with increasing compressive strength. The relationship between the compressive strength and the chord and secant moduli of elasticity for the tests of this investigation can be approximated by;

$$\begin{aligned} E_c &= 0.050 \sqrt{f_c} - 150 f_c \\ E_s &= 0.060 \sqrt{f_c} - 130 f_c \end{aligned}$$

CHAPTER 9

RECOMMENDATIONS

As was noted in Sect. 7.2., an explanation of the phenomena of strength gain at below freezing temperatures has not yet been obtained. Since the desirability of a complete explanation is obvious, this author wishes to recommend an investigation that would formulate an hypothesis on the strength gain phenomena, and then organize a testing program to substantiate it.

It is recommended that beams of three inch by three inch cross-section or smaller be limited to use in tests of fine aggregate or mortar only, due to the influence on flexural strength of chance locations of pieces of coarse aggregate.

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A P P E N D I X A

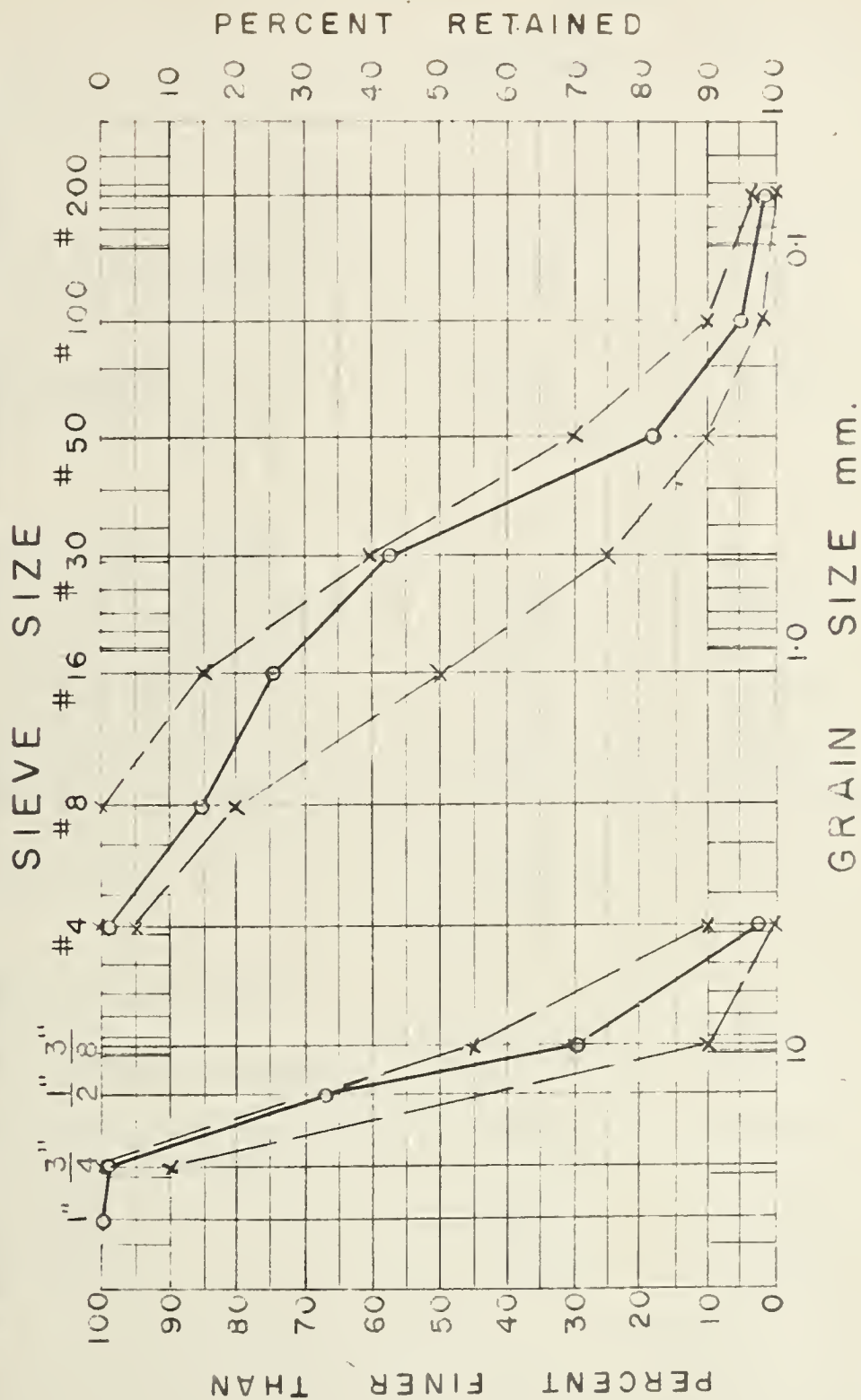
TABLE 1

PHYSICAL PROPERTIES OF AGGREGATES

Properties	A.S.T.M. Standard	Average Values
Coarse Aggregate:		
1. Unit Weight lbs./cubic foot (Basis of dry rodded weight)	C29=55 ^T	96.0
2. Bulk Specific Gravity (Saturated Surface Dry Basis)	C127-42	2.757
3. Absorption %	C127-42	1.22
Fine Aggregate:		
1. Fineness Modulus	C125-48	2.63
2. Bulk Specific Gravity (Saturated Surface Dry Basis)	C127-42	2.54
3. Absorption %	C127-42	1.36

FIG. 1

FIGURE 1
SIEVE ANALYSIS OF AGGREGATES



NOTE:

1. Dotted Lines Indicate A.S.T.M. Specifications.
2. Solid Lines Are Average Values for the Two Supplies.
3. Fine Aggregate — Fineness Modulus — 2.63
— 1.0 % Passing #200 (Washed)

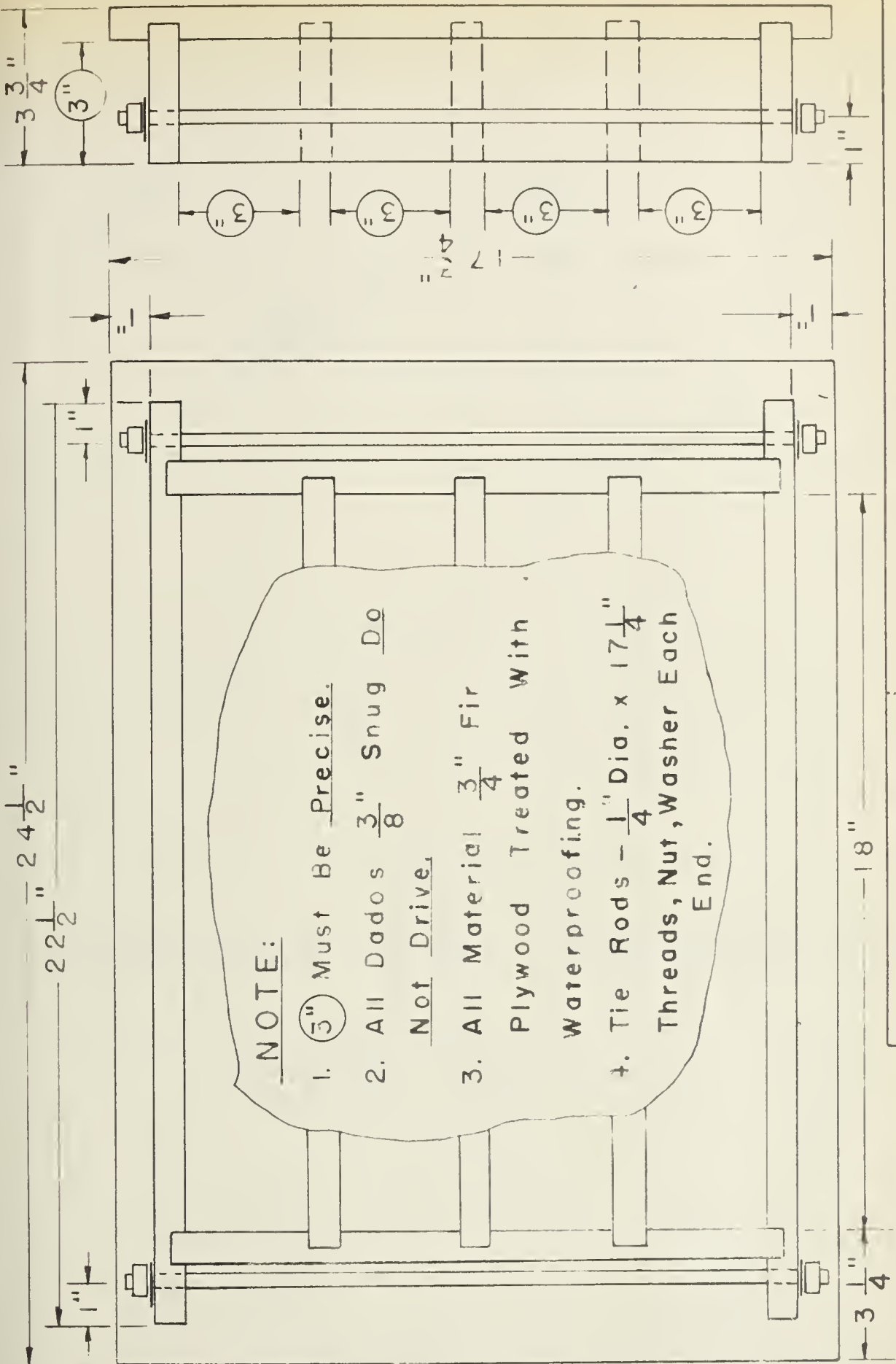
TABLE 2

FINAL MIX DESIGNS

	28 Day Design Strength*		
	2,000 psi	3,000 psi	4,000 psi
Slump	1" to 2"	1" to 2"	1" to 2"
Water-Cement Ratio W/C gal./bag	7.00	5.65	4.65
Cement Factor bag/cubic yard	4.20	5.21	6.33
1 cubic yard Batch:			
Coarse Aggregate lbs.	1625	1625	1625
Fine Aggregate lbs.	1547	1470	1390
Water lbs.	335	332	332
(Slump correction and allowance for absorption included)			
Cement lbs.	368	456	553
2 cubic foot Batch:			
Coarse Aggregate lbs.	120.4	120.4	120.4
Fine Aggregate lbs.	114.6	108.4	103.2
Water lbs.	24.6	24.6	24.6
Cement lbs.	27.2	33.8	41.0

*Designs on basis of recommendations of A.C. 613-54

FIG. 2



BEAM MOLDS
12 REQ'D.

SCALE:
 $3" = 1'-0$

DIAL READING $\times 10^{-4}$ inches

LOW

HIGH

400

150

300

100

200

50

100

1,000

500

2,000

1,000

3,000

1,500

LOAD

pounds

LOW

HIGH

PROVIN

AMERICA

ME

LOAD B

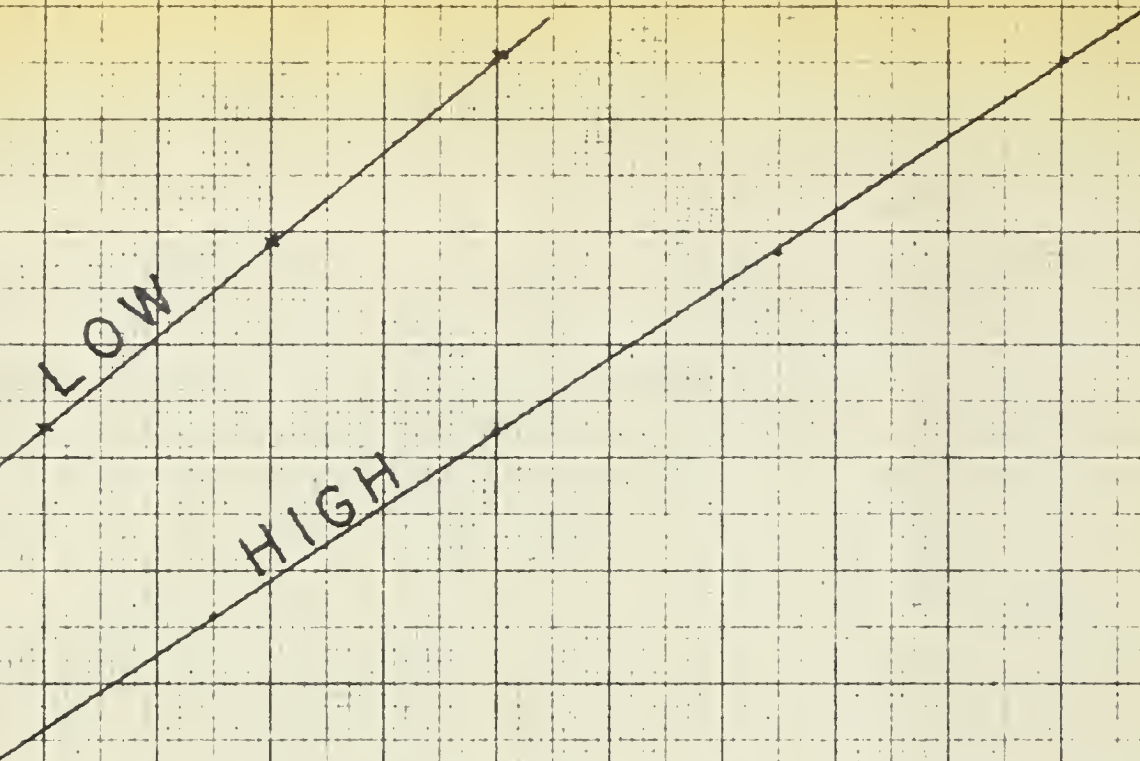


FIGURE 3

PROVING BAR CALIBRATION

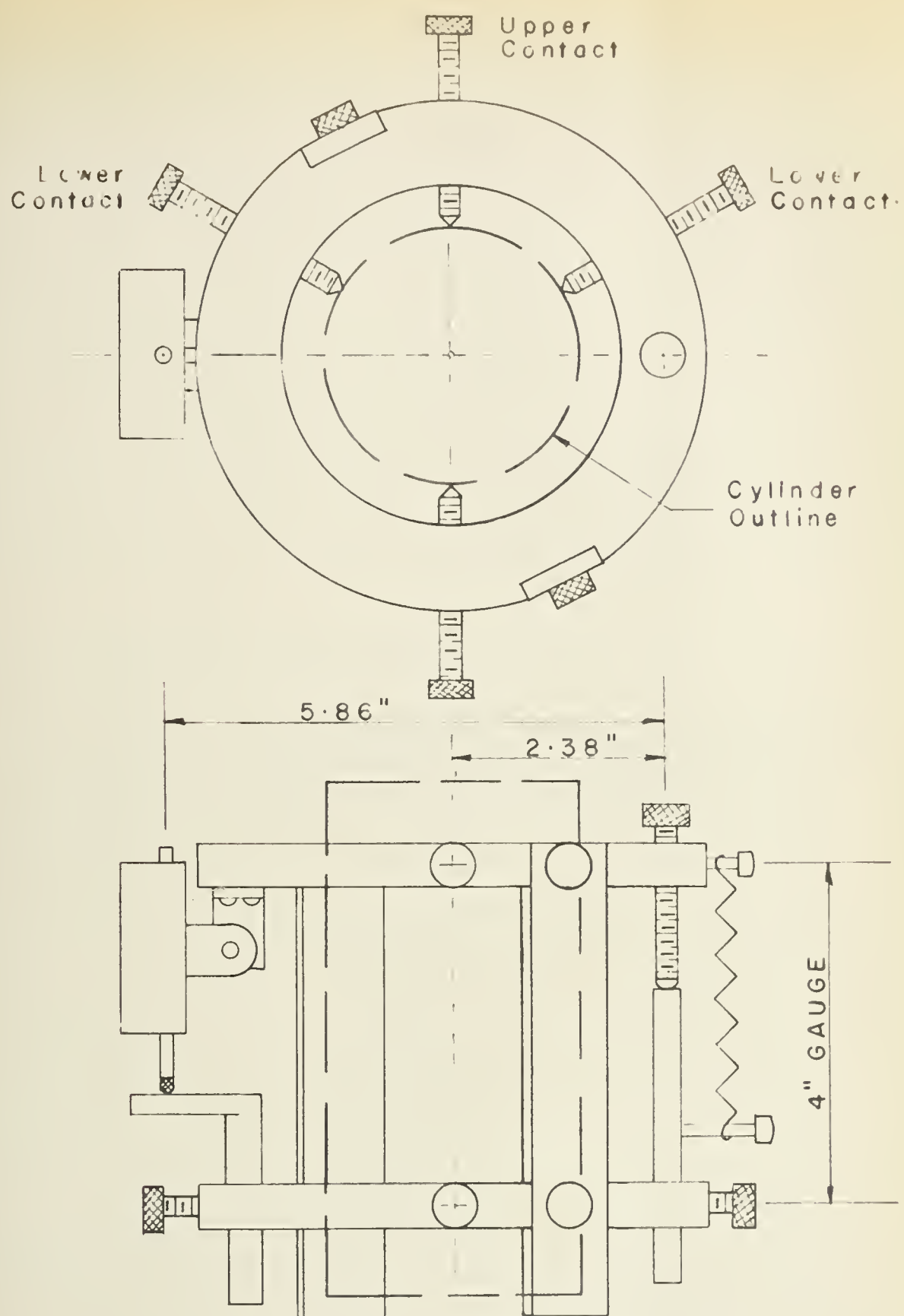
AMERICAN BEAM TESTER No. 85

MERCER 0.0001" DIAL

LOAD BY BALDWIN 20,000 pound

0	4,000	5,000	HIGH
0	2,000	2,000	LOW
ds			

FIG. 4



MULTIPLICATION FACTOR = $\frac{5.86}{2.38} = 2.46$

COMPRESSOMETER

1 REQ'D.

SCALE:
HALF SIZE

A P P E N D I X B

EXPLANATION OF DATA SHEETS

The following data sheets are summaries of test values taken from the original test data sheets. Blank spaces indicate phases of the investigation started part way through the program or results rejected due to physical defects in the specimens. In a limited number of cases, results were rejected due to non-conformity with other values of the group, as explained below.

a) Ultimate Compressive Strength

In accordance with A.C.I. 214 suggestions, values that differed from the average of the group by twice the standard deviation (S.D.) were rejected. However, this only affected one compression test result in the entire program. Compressive strength values listed on the data sheets are to 4 significant figures; this is for convenience of computation as values are actually only significant to 3 figures.

Standard cylinder tests are summarized on one sheet for each test age.

b) Strain Readings

For the purpose of stress-strain plots it was considered sufficiently accurate to use an average cylinder

diameter for computing the specimen stress. The average diameter of all cylinders tested at 2 months was computed as 2.996 inches, giving a cross sectional area of 7.059 square inches. This value was used for computing all stresses corresponding to strain readings on the following data sheets.

The average dial readings corresponding to a particular stress were used for determining the unit strain. The sum of the dial readings and the number of dial readings are included on the data sheets. The average dial reading was converted to a unit strain reading by dividing by the product of the multiplication factor, 2.462, and the gauge length, 4 inches. (See Appendix A, Fig. 4).

c) Beam Tests

As for the compressive strengths, values of the modulus of rupture differing from the group average by twice the standard deviation were rejected. Only a few values were affected.

Values of the load were obtained from Appendix A, Fig. 3, for a recorded maximum deflection reading on the beam tester dial.

The multiplication factor is composed of the

dimensional factors in the formula for the modulus of rupture. (See Sect. 3.6.).

$$f_r = \frac{Pl}{bd^2}$$

The values of b and d were measured at the failure section; l was constant at 9 inches.

The modified cube strengths are recorded opposite the beam to which they apply.

d) Moisture Contents

Values of the moisture contents indicated by "W" are shown with the group to which they apply.

STATISTICAL ANALYSIS

A statistical analysis is presented in an attempt to evaluate the reliability of test results.

The dispersion of results is generally given in terms of the standard deviation - the root mean square deviation of values from their average. In its mathematical form,

$$\Delta = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n}}$$

where Δ = standard deviation of an infinite number of samples

n = number of samples

x_i = the test value of a particular sample

$\bar{x}$ = average test value of n samples

For a small number of samples (usually taken as less than 30) the dispersion of a group is given by,

$$S. D. = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}}$$

Expressed as a percentage of the average, the standard deviation is called the coefficient of variation,

$$V = \frac{\Delta}{\bar{x}}$$

or for the small number of samples,

$$C. V. = \frac{S. D.}{\bar{x}}$$

If results are assumed to obey a normal frequency distribution, 68.3% of values will be in the range $\pm \sigma$ and 95.5% within $\pm 2\sigma$. It is realized that for the group of 6 samples in this investigation, the normal frequency distribution has limited meaning and that the computations presented are indications only.

Also included in this presentation are values of the range, R, which is the arithmetic difference between the highest and lowest values in a particular group.

A.C.I. 214-57 suggests limits of the within test coefficient of variation for various standards of concrete control. The following limits are suggested for laboratory controlled compression tests:

- i) excellent - C.V. below 3%
- ii) good - C.V. between 3% and 4%
- iii) fair - C.V. between 4% and 5%
- iv) poor - C.V. above 5%

SUMMARY OF CYLINDER TESTS

131

BATCH- 1 AGE- 7 DAYS
DATE- JULY 11, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-33° F</u> , W <u> </u> %	
0	0	0			0	1	5,503
4,000	567	38	6	7	0.70	2	6,330
8,000	1,130	92	✓	18	1.83	3	6,111
12,000	1,700	149	✓	30	3.05	4	5,932
16,000	2,270	218	✓	44	4.47	5	6,123
20,000	2,830	296 1/2	✓	59	5.99	6	5,954
24,000	3,400	389 1/2	✓	78	7.92	SUM	35,953
28,000	3,970	485 1/2	✓	97	9.85	AVE.	5,990
32,000	4,530	600	✓	120	12.18	S.D.	280
36,000	5,100	775	✓	155	15.73	C.V.	4.7
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-31° F</u> , W <u> </u> %	
0	0	0	6		0	7	7,307
5,000	708	57 1/2	✓	9 1/2	0.95	8	7,227
10,000	1,420	135	✓	22 1/2	2.28	9	7,520
15,000	2,120	221	✓	37	3.76	10	7,168
20,000	2,830	328	✓	55	5.58	11	7,463
25,000	3,540	439 1/2	✓	73	7.41	12	7,878
30,000	4,250	577	✓	96	9.74	SUM	44,563
35,000	4,960	734 1/2	✓	122	12.38	AVE.	7,430
40,000	5,670	917	✓	153	15.53	S.D.	260
45,000	6,370	949	5	190	19.29	C.V.	3.5
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-32° F</u> , W <u> </u> %	
0	0	0			0	13	8,013
5,000	708	57	6	9 1/2	0.95	14	8,532
10,000	1,420	130	✓	22	2.23	15	8,403
15,000	2,120	223	✓	37	3.76	16	8,432
20,000	2,830	325 1/2	✓	54	5.48	17	8,559
25,000	3,540	441 1/2	✓	73 1/2	7.46	18	8,304
30,000	4,250	563	✓	94	9.54	SUM	50,243
35,000	4,960	706 1/2	✓	118	11.98	AVE.	8,370
40,000	5,670	887	✓	148	15.02	S.D.	200
45,000	6,370	1035	✓	172 1/2	17.51	C.V.	2.4
50,000	7,080	825	4	206	20.92		

SUMMARY OF BEAM TESTS

BATCH - / AGE - 7 DAYS
 DATE - JULY 11, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				No TESTS
BEAM TEMP. - -28 °F				
W - %				
1 A	3,940	0.326	1,280	
B				
2 A	3,800	0.327	1,240	
B	4,320	0.322	1,390	
3 A	4,820	0.326	1,570	
B	5,770	0.328	1,890	
SUM			7,370	
AVE.			1,470	
S.D.			270	
C.V.			18.0	
3,000 p.s.i. DESIGN				
BEAM TEMP. - -28 °F				
W - %				
4 A	4,380	0.328	1,440	
B	4,580	0.328	1,500	
5 A	4,780	0.327	1,560	
B	4,840	0.335	1,620	
6 A				
B	5,080	0.324	1,650	
SUM			7,770	
AVE.			1,550	
S.D.			86	
C.V.			5.6	
4,000 p.s.i. DESIGN				
BEAM TEMP. - -28 °F				
W - %				
7 A	4,350	0.325	1,410	
B	4,080	0.325	1,330	
8 A	4,590	0.322	1,480	
B	4,030	0.326	1,310	
9 A	4,540	0.328	1,490	
B	5,210	0.328	1,710	
SUM			8,730	
AVE.			1,455	
S.D.			160	
C.V.			11.2	

SUMMARY OF CYLINDER TESTS

BATCH- 9 AGE- 7 DAYS
 DATE- AUG 26, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. -18°F, W 8.2%							
0	0	0			0	1	5,174
5,000	708	43½	5	9	0.90	2	4,776
10,000	1,420	85	✓	21	2.13	3	4,273
15,000	2,120	192	✓	38	3.86	4	4,975
20,000	2,830	299	✓	60	6.09	5	5,046
25,000	3,540	435	✓	87	8.83	6	
30,000	4,250	465	4	116	11.77	SUM	24,244
						AVE.	4,850
						S.D.	350
						C.V.	7.3
3,000 p.s.i. DESIGN Cylinder Temp. -18°F, W %							
0	0	0			0	7	6,104
5,000	708	61	6	10	1.01	8	5,944
10,000	1,420	152	✓	25	2.54	9	5,807
15,000	2,120	259½	✓	43	4.36	10	5,933
20,000	2,830	385	✓	64	6.40	11	5,960
25,000	3,540	435	✓	72½	7.36	12	6,089
30,000	4,250	715	✓	119	12.08	SUM	35,837
35,000	4,960	952	✓	159	16.14	AVE.	5,970
40,000	5,670	1,358	✓	226	22.94	S.D.	110
						C.V.	1.8
4,000 p.s.i. DESIGN Cylinder Temp. -18°F, W 6.8%							
0	0	0			0	13	6,932
5,000	708	57½	5	11½	1.17	14	7,523
10,000	1,420	135	✓	27	2.74	15	7,050
15,000	2,120	225	✓	45	4.57	16	7,594
20,000	2,830	267	4	67	6.80	17	7,478
25,000	3,540	440	5	88	8.93	18	7,780
30,000	4,250	564	✓	113	11.47	SUM	44,357
35,000	4,960	701	✓	140	14.21	AVE.	7,390
40,000	5,670	675	4	169	17.15	S.D.	330
45,000	6,370	1,074	5	215	21.82	C.V.	4.4

SUMMARY OF BEAM TESTS

BATCH - 9 AGE - 7 DAYS
DATE - AUG. 26, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-19</u> °F				
W - <u>7.6</u> %				
1 A	4,890	0.331	1,620	1,210
B	3,780	0.329	1,240	
2 A	4,670	0.321	1,500	1,140
B	4,620	0.326	1,510	
3 A	5,030	0.326	1,640	1,210
B	4,710	0.336	1,580	
SUM			9,090	3,560
AVE.			1,515	1,190
S.D.			150	
C.V.			10.1	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-18</u> °F				
W - <u>8.3</u> %				
4 A	4,000	0.326	1,300	2,250
B	4,350	0.323	1,410	
5 A	5,430	0.317	1,720	1,980
B	4,530	0.313	1,420	
6 A	4,670	0.320	1,490	2,310
B	3,770	0.321	1,210	
SUM			8,550	6,540
AVE.			1,425	2,180
S.D.			175	
C.V.			12.2	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-18</u> °F				
W - <u>6.5</u> %				
7 A	4,370	0.332	1,450	3,250
B	4,140	0.322	1,330	
8 A	4,230	0.333	1,410	2,740
B	4,230	0.337	1,430	
9 A	4,780	0.326	1,560	3,120
B	4,070	0.302	1,230	
SUM			8,410	9,110
AVE.			1,400	3,040
S.D.			110	
C.V.			7.7	

SUMMARY OF CYLINDER TESTS

135

BATCH- 2 AGE- 7 DAYS
DATE- JULY 13/60

STRESS - STRAIN

ULTIMATE

LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. -2°F, W %	
0	0	0			0	1	4,456
5,000	708	70 1/2	6	12	1.22	2	4,294
10,000	1,420	175 1/2	✓	29 1/2	2.99	3	4,645
15,000	2,120	302 1/2	✓	50	5.08	4	4,551
20,000	2,830	468	✓	78	7.92	5	4,408
25,000	3,540	676 1/2	✓	113	11.47	6	4,702
30,000	4,250	709	4	177	17.97	SUM	27,056
						AVE.	4,510
						S.D.	150
						C.V.	3.4
3,000 p.s.i. DESIGN						Cylinder Temp. -2°F, W %	
0	0	0			0	7	5,142
5,000	708	63 1/2	6	10 1/2	1.06	8	5,170
10,000	1,420	161 1/2	✓	27	2.74	9	5,269
15,000	2,120	228	5	46	4.67	10	5,692
20,000	2,830	420	6	70	7.11	11	5,635
25,000	3,540	584 1/2	✓	97 1/2	9.90	12	5,735
30,000	4,250	793	✓	132	13.40	SUM	32,643
35,000	4,960	950	5	190	19.29	AVE.	5,440
						S.D.	280
						C.V.	5.1
4,000 p.s.i. DESIGN						Cylinder Temp. -2°F, W %	
0	0	0			0	13	6,338
5,000	708	71 1/2	6	12	1.22	14	6,465
10,000	1,420	177	✓	29 1/2	2.99	15	6,479
15,000	2,120	246 1/2	5	49	4.97	16	6,331
20,000	2,830	417 1/2	6	69 1/2	7.05	17	6,602
25,000	3,540	550 1/2	✓	92	9.34	18	6,153
30,000	4,250	703 1/2	✓	117	11.88	SUM	38,368
35,000	4,960	888	✓	148	15.02	AVE.	6,390
40,000	5,670	1,146	✓	191	19.39	S.D.	160
						C.V.	2.5

SUMMARY OF BEAM TESTS

BATCH - 2 AGE - 7 DAYS

DATE - JULY 13/60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+2</u> °F W - _____ %				<u>NO TESTS</u>
1 A	4,720	0.328	1,550	
B	5,030	0.325	1,630	
2 A	5,050	0.326	1,650	
B	3,930	0.321	1,620	
3 A	5,050	0.324	1,270	
B	5,130	0.330	1,690	
SUM			9,410	
AVE.			1,570	
S.D.			150	
C.V.			9.8	
<u>3,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>0</u> °F W - _____ %				
4 A	4,660	0.326	1,520	
B	4,950	0.321	1,590	
5 A	4,840	0.326	1,580	
B	4,720	0.332	1,570	
6 A	4,720	0.325	1,530	
B	4,920	0.327	1,610	
SUM			9,400	
AVE.			1,570	
S.D.			35	
C.V.			2.2	
<u>4,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+2</u> °F W - _____ %				
7 A	3,500	0.327	1,140	
B	4,180	0.329	1,380	
8 A	4,440	0.326	1,450	
B	4,170	0.337	1,410	
9 A	4,060	0.325	1,320	
B	4,170	0.333	1,390	
SUM			8,090	
AVE.			1,350	
S.D.			110	
C.V.			8.2	

SUMMARY OF CYLINDER TESTS

137

BATCH- 8 AGE- 7 DAYS
DATE- AUG. 25/60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. $\pm 13^{\circ}\text{F}$, W <u> </u> %	
0	0	0			0	1	3,605
3,000	425	40 1/2	6	7	0.70	2	3,452
6,000	850	110	-	18	1.83	3	3,268
9,000	1,275	201	-	33 1/2	3.40	4	3,636
12,000	1,700	264	5	53	5.38	5	3,487
15,000	2,120	401	-	80	8.12	6	3,478
18,000	2,550	559	-	112	11.37	SUM	20,926
21,000	2,970	822	-	164	16.65	AVE.	3,490
						S.D.	130
						C.V.	3.8
3,000 p.s.i. DESIGN						Cylinder Temp. $\pm 13^{\circ}\text{F}$, W <u>7.3</u> %	
0	0	0			0	7	4,356
4,000	567	51	5	10	1.01	8	4,287
8,000	1,133	140	-	28	2.84	9	4,272
12,000	1,700	251	-	50	5.08	10	4,060
16,000	2,270	383	-	76 1/2	7.76	11	4,583
20,000	2,830	542	-	108	10.96	12	
24,000	3,400	761	-	152	15.43	SUM	21,558
28,000	3,970	857	4	214	21.72	AVE.	4,310
						S.D.	190
						C.V.	4.3
4,000 p.s.i. DESIGN						Cylinder Temp. $\pm 13^{\circ}\text{F}$, W <u>6.6</u> %	
0	0	0			0	13	5,234
5,000	708	97	6	16	1.62	14	5,093
10,000	1,420	234 1/2	-	39	3.96	15	5,014
15,000	2,120	398	-	66	6.60	16	4,400
20,000	2,830	592	-	98 1/2	10.00	17	4,951
25,000	3,540	828	-	138	14.01	18	4,713
30,000	4,250	1,178	-	196	19.89	SUM	29,405
						AVE.	4,900
						S.D.	290
						C.V.	6.0

SUMMARY OF BEAM TESTS

BATCH - 8 AGE - 7 DAYS

DATE - AUG. 25/60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u> BEAM TEMP. - $+14^{\circ}\text{F}$ W - 7.2%				1,510
1 A	3,870	0.332	1,280	
B	3,670	0.338	1,240	
2 A	4,420	0.326	1,440	1,630
B	3,690	0.331	1,220	
3 A	3,530	0.327	1,150	1,420
B	3,780	0.327	1,240	
		SUM	7,570	4,560
		AVE.	1,260	1,520
		S.D.	93	
		C.V.	7.4	
<u>3,000 p.s.i. DESIGN</u> BEAM TEMP. - $+14^{\circ}\text{F}$ W - 7.1%				
4 A	4,750	0.329	1,560	2,030
B	4,090	0.326	1,330	
5 A	3,800	0.326	1,240	2,080
B				
6 A	4,380	0.323	1,410	2,120
B	4,090	0.321	1,310	
		SUM	6,850	6,230
		AVE.	1,370	2,080
		S.D.	125	
		C.V.	9.1	
<u>4,000 p.s.i. DESIGN</u> BEAM TEMP. - $+14^{\circ}\text{F}$ W - 6.1%				
7 A	3,370	0.335	1,130	3,060
B	3,760	0.329	1,240	
8 A	4,030	0.323	1,300	3,160
B	3,890	0.326	1,270	
9 A	3,380	0.329	1,110	3,240
B	3,510	0.330	1,160	
		SUM	7,210	9,460
		AVE.	1,200	3,150
		S.D.	79	
		C.V.	6.6	

SUMMARY OF CYLINDER TESTS

139

BATCH- 3 AGE- 7 DAYS
DATE- JULY 15/60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. $+26^{\circ}\text{F}$, W _____ %	
0	0	0			0	1	1,973
2,000	283	4 1/2	5	8	0.80	2	2,022
4,000	567	115	-	23	2.33	3	1,988
6,000	850	209	-	42	4.26	4	2,044
8,000	1,130	343	-	69	7.00	5	2,122
10,000	1,420	505	-	101	10.25	6	2,080
12,000	1,700	849	-	170	17.26	SUM	12,229
						AVE.	2,040
						S.D.	56
						C.V.	2.8
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. $+28^{\circ}\text{F}$, W _____ %	
0	0	0			0	7	2,713
2,000	283	42	6	7	0.70	8	2,715
4,000	567	92 1/2	-	15 1/2	1.57	9	2,785
6,000	850	194	-	32	3.25	10	2,626
8,000	1,130	287	-	48	4.87	11	2,811
10,000	1,420	396	-	66	6.60	12	2,744
12,000	1,700	525	-	87 1/2	8.88	SUM	16,394
14,000	1,980	687	-	114 1/2	11.62	AVE.	2,730
16,000	2,270	439	3	146	18.82	S.D.	63
						C.V.	2.3
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. $+29^{\circ}\text{F}$, W _____ %	
0	0	0			0	13	3,440
3,000	425	70 1/2	6	12	1.22	14	3,579
6,000	850	166 1/2	-	27 1/2	2.79	15	3,766
9,000	1,275	274	-	46	4.67	16	3,259
12,000	1,700	387	-	64 1/2	6.40	17	3,347
15,000	2,120	521 1/2	-	87	8.83	18	3,418
18,000	2,550	699	-	116 1/2	11.82	SUM	20,809
21,000	2,970	778	5	156	15.80	AVE.	3,470
						S.D.	180
						C.V.	5.2

SUMMARY OF BEAM TESTS

BATCH - 3 AGE - 7 DAYS
DATE - JULY 15/60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				<u>No TESTS</u>
BEAM TEMP. - <u>+31</u> °F				
W - _____ %				
1 A	1,250	0.331	414	
B	1,190	0.326	388	
2 A	830	0.328	272	
B	1,080	0.324	350	
3 A	1,310	0.311	407	
B	1,100	0.311	342	
SUM			2,173	
AVE.			362	
S.D.			53	
C.V.			14.6	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+29½</u> °F				
W - _____ %				
4 A	1,450	0.317	460	
B				
5 A	1,360	0.331	450	
B	1,380	0.333	460	
6 A	1,550	0.324	502	
B	1,430	0.321	459	
SUM			2,331	
AVE.			466	
S.D.			20	
C.V.			4.4	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+29</u> °F				
W - _____ %				
7 A	1,540	0.314	484	
B	1,480	0.330	488	
8 A	1,480	0.326	482	
B	1,410	0.323	455	
9 A	1,440	0.327	471	
B	1,420	0.326	463	
SUM			2,843	
AVE.			474	
S.D.			13	
C.V.			2.8	

SUMMARY OF CYLINDER TESTS

141

BATCH- 10 AGE- 7 DAYS
DATE- SEPT 13, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. $+49^{\circ}\text{F}$, W 7.1 %	
0	0	0			0	1	1,204
1,000	142	29	5	6	0.60	2	1,217
2,000	283	70	-	14	1.42	3	1,239
3,000	425	110	-	22	2.23	4	1,467
4,000	567	181 1/2	-	36	3.65	5	1,314
5,000	708	270	-	54	5.48	6	1,256
6,000	850					SUM	7,697
7,000	992	466	4	116 1/2	11.82	AVE.	1,280
8,000	1,133	833 1/2	5	167	16.95	S.D.	100
						C.V.	7.8
3,000 p.s.i. DESIGN						Cylinder Temp. $+49^{\circ}\text{F}$, W 8.6 %	
0	0	0			0	7	2,260
2,000	283	59 1/2	6	10	1.01	8	2,058
4,000	567	144	-	24	2.44	9	1,962
6,000	850	241	-	40	4.06	10	2,179
8,000	1,133	351 1/2	-	59 1/2	6.04	11	2,292
10,000	1,420	499	-	83	8.42	12	2,278
12,000	1,700	688	-	115	11.67	SUM	13,029
14,000	1,980	765	5	153	15.53	AVE.	2,170
						S.D.	135
						C.V.	6.2
4,000 p.s.i. DESIGN						Cylinder Temp. $+49^{\circ}\text{F}$, W 6.9 %	
0	0	0			0	13	3,225
3,000	425	70 1/2	6	12	1.22	14	3,695
6,000	850	174 1/2	-	29	2.94	15	3,650
9,000	1,275	286 1/2	-	48	4.87	16	3,600
12,000	1,700	415	-	69	7.00	17	
15,000	2,120	557	-	93	9.44	18	3,380
18,000	2,550	601	5	120	12.18	SUM	1,755
21,000	2,970	773 1/2	6	155	15.73	AVE.	3,510
						S.D.	200
						C.V.	5.7

SUMMARY OF BEAM TESTS

BATCH - 10 AGE - 7 DAYS

DATE - SEPT. 13, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
2,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 7.0%				
1 A				1,660
B				
2 A	410	0.320	131	1,690
B	490	0.322	158	
3 A	450	0.329	148	2,010
B	475	0.316	150	
SUM			587	5,360
AVE.			147	1,790
S.D.			11	
C.V.			7.7	
3,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 6.4%				
4 A	690	0.323	223	2,380
B	660	0.333	220	
5 A	670	0.317	212	2,440
B	860	0.307	264	
6 A	635	0.312	198	2,750
B	710	0.312	222	
SUM			1,339	7,570
AVE.			223	2,520
S.D.			22	
C.V.			10.0	
4,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 6.1%				
7 A	1,065	0.301	321	4,150
B	1,075	0.306	329	
8 A	1,030	0.320	330	4,070
B	1,140	0.315	359	
9 A	930	0.322	299	4,010
B	785	0.332	261	
SUM			1,899	12,230
AVE.			317	4,080
S.D.			37	
C.V.			11.8	

SUMMARY OF CYLINDER TESTS

BATCH- 4 AGE- 7 DAYS
DATE- JULY 19, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. $\pm 78^{\circ}\text{F}$, W _____ %							
0	0	0		0	0	1	1,301
2,000	283	66	6	11	1.12	2	1,316
4,000	567	163	✓	27	2.74	3	1,273
6,000	850	292	✓	49	4.97	4	1,462
8,000	1,133	541	✓	90	9.14	5	1,278
						6	1,344
						SUM	7,974
						AVE.	1,330
						S.D.	70
						C.V.	5.3
3,000 p.s.i. DESIGN Cylinder Temp. $\pm 78^{\circ}\text{F}$, W _____ %							
0	0			0	0	7	2,278
2,000	283	57 1/2	6	9 1/2	0.95	8	2,350
4,000	567	126 1/2	✓	21	2.13	9	2,214
6,000	850	217	✓	36	3.65	10	2,358
8,000	1,133	299	✓	50	5.08	11	2,409
10,000	1,420	414	✓	69	7.00	12	2,330
12,000	1,700	557	✓	93	9.44	SUM	13,939
14,000	1,980	482	4	120 1/2	12.23	AVE.	2,320
						S.D.	70
						C.V.	3.0
4,000 p.s.i. DESIGN Cylinder Temp. $\pm 78^{\circ}\text{F}$, W _____ %							
0	0	0			0	13	3,322
3,000	425	79	6	13	1.32	14	3,066
6,000	850	181	✓	30	3.05	15	2,858
9,000	1,275	291	✓	48 1/2	4.92	16	3,194
12,000	1,700	413	✓	69	7.00	17	3,293
15,000	2,120	558	✓	93	9.44	18	3,290
18,000	2,550	753	✓	125 1/2	12.74	SUM	19,023
						AVE.	3,170
						S.D.	180
						C.V.	5.6

SUMMARY OF BEAM TESTS

BATCH - 4 AGE - 7 DAYS
DATE - JULY 19, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+72</u> °F W - _____ %				<u>No Tests</u>
1 A	530	0.324	172	
B	470	0.326	153	
2 A	515	0.327	168	
B	480	0.325	156	
3 A	420	0.331	139	
B	410	0.333	137	
SUM			925	
AVE.			154	
S.D.			14	
C.V.			9.4	
<u>3,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+72</u> °F W - _____ %				
4 A	770	0.322	248	
B	810	0.327	265	
5 A	820	0.326	267	
B	740	0.327	242	
6 A	760	0.330	251	
B	850	0.327	278	
SUM			1,551	
AVE.			258	
S.D.			14	
C.V.			5.3	
<u>4,000 p.s.i. DESIGN</u> BEAM TEMP. - _____ °F W - _____ %				
7 A	1,150	0.326	375	
B	1,150	0.326	375	
8 A	1,000	0.332	332	
B	1,030	0.330	340	
9 A	1,270	0.319	405	
B	1,070	0.325	348	
SUM			2,175	
AVE.			362	
S.D.			28	
C.V.			7.6	

SUMMARY OF STANDARD

CYLINDER TESTS

AGE - 7 DAYS

BATCH	CYL. NO.	ULTIMATE STRENGTH p.s.i.		
		2,000 p.s.i. DESIGN	3,000 p.s.i. DESIGN	4,000 p.s.i. DESIGN
8	1 S	1,110	2,040	3,210
	2 S		2,040	3,160
	3 S	1,210	2,220	3,110
	SUM	2,320	6,300	9,480
	AVE.	1,160	2,100	3,160
9	1 S	1,210	1,620	3,080
	2 S	934	1,970	3,110
	3 S	852		3,020
	SUM	2,996	3,590	9,210
	AVE.	1,000	1,795	3,070
10	1 S	1,260	2,070	3,460
	2 S	1,250	2,190	2,940
	3 S	1,240	1,830	2,760
	SUM	3,750	6,090	9,160
	AVE.	1,250	2,030	3,050

SUMMARY OF CYLINDER TESTS

146

BATCH- 1 AGE- 28 DAYS
DATE- AUG. 1, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. -31°F, W _____ %							
0	0				0	1	6,673
5,000	708	53	6	8 1/2	0.85	2	6,863
10,000	1,420	125 1/2	-	21	2.13	3	7,949
15,000	2,120	229 1/2	-	38	3.86	4	7,251
20,000	2,830	350 1/2	-	58	5.89	5	7,250
25,000	3,540	503	-	84	8.52	6	6,814
30,000	4,250	675	-	112 1/2	11.4	SUM	42,800
35,000	4,960	874	-	146	14.8	AVE.	7,130
40,000	5,670	1118	-	186	18.9	S.D.	470
						C.V.	6.5
3,000 p.s.i. DESIGN Cylinder Temp. -31°F, W _____ %							
0	0				0	7	8,500
5,000	708	50 1/2	6	8 1/2	0.85	8	8,047
10,000	1,420	123	-	20 1/2	2.08	9	8,371
15,000	2,120	182	5	36	3.65	10	8,902
20,000	2,830	347 1/2	6	58	5.89	11	8,744
25,000	3,540	479	-	80	8.12	12	8,872
30,000	4,250	629	-	105	10.66	SUM	51,436
35,000	4,960	797	-	133	13.50	AVE.	8,570
40,000	5,670	970	-	162	16.44	S.D.	330
45,000	6,370	1176	-	196	19.89	C.V.	3.8
4,000 p.s.i. DESIGN Cylinder Temp. -31°F, W 6.8 %							
0	0				0	13	9,700
5,000	708	47 1/2	5	9 1/2	0.95	14	9,648
10,000	1,420	113 1/2	-	22 1/2	2.28	15	
15,000	2,120	196	-	39	3.96	16	10,610
20,000	2,830	234	-	47	4.77	17	10,271
25,000	3,540	400	-	80	8.12	18	10,257
30,000	4,250	506	-	101	10.25	SUM	50,486
35,000	4,960	622	-	124	12.59	AVE.	10,100
40,000	5,670	740	-	148	15.02	S.D.	400
45,000	6,370	865	-	173	17.56	C.V.	4.0
50,000	7,080	807	-	202	20.50		

SUMMARY OF BEAM TESTS

BATCH - 1 AGE - 28 DAYS
DATE - AUG 1, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				
BEAM TEMP. - -22°F				
W - 7.1 %				
1 A	4,660	0.322	1,500	2,630
B	4,710	0.320	1,510	
2 A	4,380	0.337	1,480	2,500
B	4,600	0.334	1,540	
3 A	4,750	0.330	1,570	7,620
B	4,890	0.331	1,620	
		SUM	9,220	2,540
		AVE.	1,540	
		S.D.	52	
		C.V.	3.4	
3,000 p.s.i. DESIGN				
BEAM TEMP. - -21°F				
W - %				
4 A	4,130	0.327	1,350	3,600
B	4,170	0.327	1,360	
5 A				3,970
B	3,580	0.329	1,180	
6 A				3,490
B	3,700	0.329	1,220	
		SUM	5,110	11,060
		AVE.	1,280	3,690
		S.D.		
		C.V.		
4,000 p.s.i. DESIGN				
BEAM TEMP. - -18°F				
W - 6.1 %				
7 A	4,080	0.329	1,340	5,020
B	3,650	0.326	1,190	
8 A	4,230	0.327	1,380	4,690
B	4,120	0.328	1,350	
9 A	3,490	0.329	1,140	5,080
B	4,250	0.334	1,420	
		SUM	7,820	14,790
		AVE.	1,300	4,930
		S.D.	110	
		C.V.	8.6	

SUMMARY OF CYLINDER TESTS

148

BATCH- 9 AGE- 28 DAYS
DATE- SEPT. 16, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. -18°F, W _____ %	
0	0				0	1	5,507
4,000	567	29 1/2	4	7 1/2	0.75	2	4,055
8,000	1,130	98 1/2	5	20	2.03	3	5,618
12,000	1,700	146 1/2	4	37	3.76	4	4,697
16,000	2,270	296 1/2	5	59	5.99	5	5,574
20,000	2,830	399	-	80	8.12	6	6,075
24,000	3,400	531 1/2	-	106	10.76	SUM	31,526
28,000	3,970	545	4	136	13.80	AVE.	5,250
32,000	4,530	687	-	172	17.46	S.D.	730
36,000	5,100	607	3	202	20.50	C.V.	14.0
3,000 p.s.i. DESIGN						Cylinder Temp. -18°F, W _____ %	
0	0				0	7	7,762
5,000	708	65 1/2	6	11	1.12	8	7,866
10,000	1,420	149	-	25	2.54	9	7,710
15,000	2,120	247 1/2	-	41	4.16	10	7,807
20,000	2,830	361 1/2	-	60	6.09	11	8,092
25,000	3,540	505 1/2	-	84	8.52	12	7,878
30,000	4,250	615	-	102 1/2	10.40	SUM	47,115
35,000	4,960	762 1/2	-	127	12.89	AVE.	7,850
40,000	5,670	919 1/2	-	158	16.04	S.D.	130
45,000	6,370	1,123 1/2	-	187	18.98	C.V.	1.7
4,000 p.s.i. DESIGN						Cylinder Temp. -18°F, W _____ %	
0	0				0	13	9,400
5,000	708	56	6	9	0.90	14	9,506
10,000	1,420	135 1/2	-	22 1/2	2.28	15	9,510
15,000	2,120	229	-	38	3.96	16	9,973
20,000	2,830	335 1/2	-	56	5.68	17	10,110
25,000	3,540	444 1/2	-	74	7.51	18	9,704
30,000	4,250	566	-	94	9.54	SUM	58,206
35,000	4,960	689	-	115	11.67	AVE.	9,700
40,000	5,670	818	-	136	13.80	S.D.	280
45,000	6,370	974	-	162	16.44	C.V.	2.9
50,000	7,080	1,132 1/2	-	189	19.18		
55,000	7,790	1,291	-	215	21.82		
60,000	8,500	978	4	244 1/2	24.80		

SUMMARY OF BEAM TESTS

 BATCH - 9 AGE - 28 DAYS

 DATE - SEPT 16, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
2,000 p.s.i. DESIGN				
BEAM TEMP. - -18°F				
W - %				
1 A	4,400	0.316	1,390	2,390
B	4,720	0.307	1,450	
2 A	3,920	0.322	1,260	2,200
B	4,350	0.335	1,460	
3 A	4,080	0.325	1,330	2,010
B	3,870	0.330	1,280	
		SUM	8,170	6,600
		AVE.	1,360	2,200
		S.D.	85	
		C.V.	6.3	
3,000 p.s.i. DESIGN				
BEAM TEMP. - -18°F				
W - %				
4 A	4,500	0.329	1,480	3,550
B	4,300	0.324	1,390	
5 A	4,230	0.326	1,380	3,660
B	3,860	0.335	1,290	
6 A	4,600	0.318	1,460	3,210
B	4,180	0.324	1,350	
		SUM	8,350	10,420
		AVE.	1,390	3,470
		S.D.	70	
		C.V.	5.0	
4,000 p.s.i. DESIGN				
BEAM TEMP. - -18°F				
W - %				
7 A	4,430	0.329	1,460	4,880
B	4,540	0.322	1,460	
8 A	3,870	0.330	1,280	4,510
B	3,730	0.330	1,230	
9 A	4,640	0.324	1,500	4,100
B	4,100	0.328	1,340	
		SUM	8,270	13,490
		AVE.	1,380	4,500
		S.D.	110	
		C.V.	8.0	

SUMMARY OF CYLINDER TESTS

150

BATCH- 7 AGE- 28 DAYS
DATE- AUG. 26, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u> </u> %							
						1	5,432
						2	5,259
						3	5,644
						4	5,460
						5	5,503
						6	5,842
						SUM	33,140
						AVE.	5,520
						S.D.	200
						C.V.	3.6
<u>3,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-19°F</u> , W <u>5.4</u> %							
						7	7,063
						8	7,568
						9	7,441
						10	7,722
						11	7,582
						12	7,480
						SUM	44,856
						AVE.	7,410
						S.D.	240
						C.V.	3.2
<u>4,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-20°F</u> , W <u>5.2</u> %							
						13	9,195
						14	9,031
						15	8,841
						16	8,967
						17	9,084
						18	8,900
						SUM	54,018
						AVE.	9,030
						S.D.	130
						C.V.	1.5

SUMMARY OF BEAM TESTS

BATCH - 7 AGE - 28 DAYS

DATE - AUG. 26, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-18° F</u>				
W - <u>5.0%</u>				
1 A	3,550	0.320	816	2,070
B	2,220	0.318	706	
2 A	3,680	0.319	1,170	2,240
B	3,450	0.327	1,130	
3 A	3,160	0.319	1,010	2,230
B	3,440	0.319	1,100	
		SUM	5,932	6,540
		AVE.	989	2,180
		S.D.	190	
		C.V.	19.0	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-18° F</u>				
W - <u>4.2%</u>				
4 A	3,450	0.322	1,110	3,510
B	3,870	0.316	1,220	
5 A	3,320	0.335	1,110	3,700
B	3,500	0.327	1,140	
6 A	3,450	0.316	1,090	3,640
B	3,730	0.321	1,160	
		SUM	6,830	10,850
		AVE.	1,140	3,620
		S.D.	47	
		C.V.	4.1	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-18° F</u>				
W - <u>4.2%</u>				
7 A	3,160	0.323	1,020	4,420
B	3,490	0.327	1,140	
8 A	3,580	0.322	1,150	4,470
B	2,920	0.336	981	
9 A	3,380	0.315	1,060	4,420
B	3,180	0.322	1,020	
		SUM	6,370	13,310
		AVE.	1,060	4,440
		S.D.	69	
		C.V.	6.5	

SUMMARY OF CYLINDER TESTS

BATCH- 2 AGE- 28 DAYS
DATE- AUG 3, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. 0°F , W 7.1 %	
0	0				0	1	5,071
5,000	708	60	6	10	1.01	2	4,842
10,000	1,420	150	-	25	2.54	3	5,400
15,000	2,120	263	-	44	4.47	4	5,191
20,000	2,830	393 1/2	-	65 1/2	6.55	5	5,000
25,000	3,540	549	-	91 1/2	9.49	6	5,202
30,000	4,250	751	-	125	12.69	SUM	30,706
35,000	4,960	328	2	164	16.65	AVE.	5,120
						S.D.	190
						C.V.	3.8
3,000 p.s.i. DESIGN						Cylinder Temp. $\pm/$ $^{\circ}\text{F}$, W 7.3 %	
0	0				0	7	6,552
5,000	708	58	6	10	1.01	8	6,808
10,000	1,420	146	-	24	2.44	9	6,536
15,000	2,120	264	-	44	4.47	10	6,979
20,000	2,830	319	5	63	6.39	11	6,865
25,000	3,540	430	-	86	8.73	12	6,500
30,000	4,250	552	-	110	11.17	SUM	40,240
35,000	4,960	692	-	138	14.01	AVE.	6,710
40,000	5,670	864	-	173	17.56	S.D.	200
						C.V.	3.0
4,000 p.s.i. DESIGN						Cylinder Temp. $\pm/$ $^{\circ}\text{F}$, W %	
0	0				0	13	8,119
5,000	708	71 1/2	6	12	1.22	14	8,332
10,000	1,420	154 1/2	-	26	2.64	15	8,558
15,000	2,120	254	-	42	4.26	16	
20,000	2,830	361	-	60	6.09	17	8,317
25,000	3,540	465	-	76 1/2	7.76	18	8,177
30,000	4,250	576 1/2	-	96	9.74	SUM	41,503
35,000	4,960	700	-	117	11.88	AVE.	8,300
40,000	5,670	836	-	139	14.11	S.D.	170
45,000	6,370	998	-	166	16.85	C.V.	2.0
50,000	7,080	1,117	-	196	19.89		

SUMMARY OF BEAM TESTS

BATCH - 2 AGE - 28 DAYS

DATE - AUG. 3, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				
BEAM TEMP. - $+6^{\circ}\text{F}$				
W - 6.7%				
1 A	4,640	0.326	1,510	2,250
B	3,630	0.324	1,180	
2 A	4,330	0.327	1,420	2,220
B	4,450	0.326	1,450	
3 A	4,010	0.326	1,310	1,930
B	3,630	0.322	1,170	
		SUM	8,040	6,400
		AVE.	1,340	2,130
		S.D.	140	
		C.V.	10.7	
3,000 p.s.i. DESIGN				
BEAM TEMP. - $+2^{\circ}\text{F}$				
W - %				
4 A	4,130	0.327	1,350	3,980
B	4,230	0.328	1,390	
5 A	4,420	0.330	1,460	3,680
B	4,650	0.329	1,530	
6 A	4,740	0.328	1,550	3,620
B	4,420	0.327	1,450	
		SUM	8,730	11,280
		AVE.	1,455	3,760
		S.D.	78	
		C.V.	5.3	
4,000 p.s.i. DESIGN				
BEAM TEMP. - $+3^{\circ}\text{F}$				
W - 5.0%				
7 A	3,950	0.336	1,330	3,800
B	4,280	0.328	1,400	
8 A	4,710	0.328	1,540	4,500
B	4,500	0.330	1,490	
9 A	4,430	0.334	1,480	4,490
B	4,620	0.329	1,520	
		SUM	8,760	12,790
		AVE.	1,460	4,260
		S.D.	110	
		C.V.	7.4	

SUMMARY OF CYLINDER TESTS

BATCH- 8 AGE- 28 DAYS
DATE- SEPT. 15, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 13^{\circ}\text{F}$, W <u>6.6%</u>	
0	0				0	1	4,272
3,000	425	40	5	8	0.90	2	4,514
6,000	850	97½	-	19½	1.98	3	4,273
9,000	1,275	162½	-	32½	3.30	4	4,429
12,000	1,700	240½	-	48	4.87	5	4,372
15,000	2,120	327	-	65	6.50	6	
18,000	2,550	427	-	85	8.63	SUM	21,860
21,000	2,970	544½	-	109	11.06	AVE.	4,370
24,000	3,400	684	-	133	13.50	S.D.	93
27,000	3,820	700½	4	175	17.76	C.V.	2.1
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 13^{\circ}\text{F}$, W <u>7.3%</u>	
0	0				0	7	5,227
5,000	708	88½	6	15	1.52	8	6,166
10,000	1,420	185	-	31	3.15	9	6,061
15,000	2,120	327	-	54½	5.53	10	6,203
20,000	2,830	482	-	80	8.12	11	5,931
25,000	3,540	646	-	108	10.96	12	6,069
30,000	4,250	839½	-	140	14.21	SUM	35,657
35,000	4,960	1139	5	190	19.29	AVE.	5,940
40,000	5,670					S.D.	360
						C.V.	6.1
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 16^{\circ}\text{F}$, W <u> %</u>	
0	0				0	13	6,529
5,000	708	87	6	14½	1.47	14	7,002
10,000	1,420	198½	-	33	3.35	15	6,716
15,000	2,120	315½	-	52½	5.33	16	7,002
20,000	2,830	442½	-	74	7.51	17	6,884
25,000	3,540	580	-	97	9.85	18	7,073
30,000	4,250	727½	-	121	12.28	SUM	41,206
35,000	4,960	872½	-	145	14.72	AVE.	6,870
40,000	5,670	1053	-	175	17.81	S.D.	210
						C.V.	3.0

SUMMARY OF BEAM TESTS

BATCH - 8 AGE - 28 DAYS
DATE - SEPT 15, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN BEAM TEMP. - $\pm 13^{\circ}\text{F}$ W - 6.9%				
1 A	3,830	0.317	1,210	2,550
B	3,980	0.316	1,260	
2 A	4,010	0.328	1,320	2,290
B	3,910	0.333	1,300	
3 A	3,510	0.324	1,140	2,440
B	3,930	0.324	1,270	
		SUM	7,500	7,280
		AVE.	1,250	2,430
		S.D.	66	
		C.V.	5.3	
3,000 p.s.i. DESIGN BEAM TEMP. - $\pm 13^{\circ}\text{F}$ W - 6.9%				
4 A	3,240	0.337	1,090	3,160
B	3,820	0.329	1,260	
5 A	3,750	0.325	1,220	3,760
B	3,500	0.332	1,160	
6 A	3,370	0.328	1,110	3,500
B	4,380	0.327	1,430	
		SUM	7,270	10,420
		AVE.	1,210	3,440
		S.D.	125	
		C.V.	10.3	
4,000 p.s.i. DESIGN BEAM TEMP. - $\pm 13^{\circ}\text{F}$ W - 5.7%				
7 A	3,570	0.325	1,160	4,930
B	3,610	0.318	1,150	
8 A	3,420	0.339	1,160	4,640
B	3,680	0.339	1,250	
9 A	3,480	0.338		4,650
B	4,010	0.338	1,360	
		SUM	6,070	14,220
		AVE.	1,210	4,740
		S.D.	87	
		C.V.	7.2	

SUMMARY OF CYLINDER TESTS

156

BATCH- 3 AGE- 28 DAYS
DATE- AUG. 5, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. +33°F, W 6.3 %	
0	0				0	1	2,589
3,000	425	60 1/2	5	12	1.22	2	2,792
6,000	850	137	✓	27	2.74	3	2,735
9,000	1,275	234	✓	47	4.77	4	2,735
12,000	1,700	347	✓	69	7.00	5	2,671
15,000	2,120	500	✓	100	10.15	6	
18,000	2,550	433	3	144	14.62	SUM	13,522
						AVE.	2,700
						S.D.	79
						C.V.	2.9
3,000 p.s.i. DESIGN						Cylinder Temp. +31°F, W 6.2 %	
0	0				0	7	3,974
3,000	425	46 1/2	5	9	0.90	8	4,129
6,000	850	114	✓	23	2.33	9	3,504
9,000	1,275	191	✓	38	3.86	10	3,843
12,000	1,700	213	4	53	5.38	11	
15,000	2,120	350	✓	70	7.11	12	3,929
18,000	2,550	444	✓	89	9.03	SUM	19,379
21,000	2,970	556	✓	111	11.27	AVE.	3,880
24,000	3,400	538	4	134 1/2	13.65	S.D.	240
						C.V.	6.2
4,000 p.s.i. DESIGN						Cylinder Temp. +30°F, W 5.2 %	
0	0				0	13	5,291
4,000	567	76	6	12 1/2	1.27	14	4,658
8,000	1,130	176 1/2	✓	29 1/2	2.99	15	4,784
12,000	1,700	281	✓	47	4.77	16	4,700
16,000	2,270	390	✓	65	6.50	17	5,583
20,000	2,830	506 1/2	✓	84 1/2	8.57	18	5,327
24,000	3,400	637	✓	106	10.76	SUM	30,343
28,000	3,970	662	5	132	13.40	AVE.	5,060
32,000	4,530	837	5	167	16.95	S.D.	400
						C.V.	8.0

SUMMARY OF BEAM TESTS

BATCH - 3 AGE - 28 DAYS

DATE - Aug. 5, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+32° F</u>				
W - <u>61 %</u>				
1 A	1,030	0.321	331	2,500
B	1,100	0.331	344	
2 A	870	0.320	278	
B	850	0.332	274	
3 A	980	0.327	320	2,550
B	1,070	0.332	355	
		SUM	1,902	
		AVE.	317	
		S.D.	34	
		C.V.	10.7	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+32° F</u>				
W - <u>5.5 %</u>				
4 A	1,140	0.326	372	3,610
B	1,170	0.323	378	
5 A	1,160	0.325	377	3,430
B	1,310	0.327	428	
6 A	1,160	0.320	371	3,810
B	1,140	0.328	374	
		SUM	2,300	10,850
		AVE.	363	
		S.D.	31	
		C.V.	8.6	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+29° F</u>				
W - <u>4.5 %</u>				
7 A	1,630	0.315	513	4,540
B	1,490	0.325	484	
8 A	1,450	0.325	471	4,730
B	1,480	0.324	480	
9 A	1,620	0.321	520	3,910
B	1,570	0.324	509	
		SUM	2,277	13,180
		AVE.	496	
		S.D.	20	
		C.V.	4.0	

SUMMARY OF CYLINDER TESTS

158

BATCH- 10 AGE- 28 DAYS
DATE- OCT. 4, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. $+49^{\circ}\text{F}$, W 6.9%							
0	0				0	1	2,546
3,000	425	54 1/2	5	9	0.90	2	2,699
6,000	850	169	6	28	2.84	3	2,532
9,000	1,275	233	5	46 1/2	4.72	4	2,440
12,000	1,700	415	6	69	7.05	5	2,494
15,000	2,120	405	4	101	10.25	6	2,450
						SUM	15,893
						AVE.	2,650
						S.D.	165
						C.V.	6.2
3,000 p.s.i. DESIGN Cylinder Temp. $+49^{\circ}\text{F}$, W 7.0%							
0	0				0	7	3,561
3,000	425	61 1/2	6	10	1.01	8	3,776
6,000	850	150	-	25	2.54	9	2,977
9,000	1,275	256	-	43	4.36	10	3,376
12,000	1,700	366	-	61	6.19	11	3,753
15,000	2,120	481 1/2	-	80	8.12	12	3,589
18,000	2,550	447	4	112	11.38	SUM	21,032
21,000	2,970	672	5	134	13.60	AVE.	3,510
						S.D.	300
						C.V.	8.4
4,000 p.s.i. DESIGN Cylinder Temp. $+49^{\circ}\text{F}$, W 6.2%							
0	0				0	13	4,686
4,000	567	81 1/2	6	13 1/2	1.37	14	4,736
8,000	1,133	185	-	31	3.15	15	4,838
12,000	1,700	243 1/2	5	49	4.97	16	4,287
16,000	2,270	346 1/2	-	69	7.00	17	4,555
20,000	2,830	552	6	92	9.35	18	6,110
24,000	3,400	466	4	116 1/2	11.81	SUM	29,212
28,000	3,970	884	6	147	14.91	AVE.	4,870
						S.D.	630
						C.V.	13.0

SUMMARY OF BEAM TESTS

BATCH - 10 AGE - 28 DAYS
DATE - OCT. 4, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+49° F</u>				
W - <u>6.4 %</u>				
1 A	738	0.327	241	2,710
B	891	0.325	290	
2 A	1,200	0.307	368	3,460
B	1,125	0.310	349	
3 A				2,550
B	969	0.317	307	
		SUM	1,555	8,720
		AVE.	311	2,910
		S.D.	50	
		C.V.	16.1	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+49° F</u>				
W - <u>6.8 %</u>				
4 A	991	0.330	327	3,720
B	881	0.325	286	
5 A	1,210	0.313	379	3,620
B	1,240	0.310	384	
6 A	820	0.321	263	3,750
B	855	0.323	276	
		SUM	1,915	11,090
		AVE.	319	3,700
		S.D.	53	
		C.V.	16.6	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+49° F</u>				
W - <u>6.3 %</u>				
7 A	1,380	0.318	439	4,400
B	1,445	0.323	467	
8 A	1,310	0.324	424	4,770
B	1,080	0.328	354	
9 A	1,400	0.320	448	4,110
B	1,360	0.327	445	
		SUM	2,577	13,280
		AVE.	430	4,420
		S.D.	39	
		C.V.	9.2	

SUMMARY OF CYLINDER TESTS

160

BATCH- 4 AGE- 28 DAYS
DATE- AUG. 9, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 77^{\circ}\text{F}$, W <u>6.2%</u>	
0	0				0	1	2,635
3,000	425	84	6	14	1.42	2	2,535
6,000	850	193	-	32	3.25	3	2,385
9,000	1,275	326	-	54	5.48	4	2,564
12,000	1,700	501	-	83 1/2	8.47	5	2,194
15,000	2,120	598	5	120	12.18	6	2,595
						SUM	14,908
						AVE.	2,480
						S.D.	170
						C.V.	6.8
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 77^{\circ}\text{F}$, W <u>6.1%</u>	
0	0				0	7	3,872
3,000	425	61 1/2	6	10	1.01	8	3,874
6,000	850	143 1/2	-	24	2.44	9	4,230
9,000	1,275	230 1/2	-	38	3.86	10	4,186
12,000	1,700	334	-	56	5.68	11	3,888
15,000	2,120	415	-	69	7.00	12	4,600
18,000	2,550	529	-	88	8.93	SUM	24,650
21,000	2,970	655	-	109	11.06	AVE.	4,110
24,000	3,400	826	-	138	14.01	S.D.	290
						C.V.	7.1
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 77^{\circ}\text{F}$, W <u>5.6%</u>	
0	0				0	13	5,564
4,000	567	86	6	14 1/2	1.47	14	5,465
8,000	1,133	189	-	31 1/2	3.20	15	5,248
12,000	1,700	301	-	50	5.08	16	5,067
16,000	2,270	420	-	70	7.11	17	5,469
20,000	2,830	561	-	93 1/2	9.49	18	5,412
24,000	3,400	687	-	114 1/2	11.62	SUM	32,225
28,000	3,970	836	-	139	14.11	AVE.	5,370
32,000	4,530	1,030	-	172	17.46	S.D.	180
						C.V.	3.4

SUMMARY OF BEAM TESTS

BATCH - 4 AGE - 28 DAYS
 DATE - AUG. 9, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+75° F</u> W - <u>5.6 %</u>				
1 A	850	0.320	272	2,640
B	930	0.329	306	
2 A	830	0.320	266	2,910
B	830	0.320	266	
3 A	1,070	0.314	336	2,530
B	880	0.315	277	
		SUM	1,723	8,080
		AVE.	287	2,690
		S.D.	28	
		C.V.	9.8	
<u>3,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+75° F</u> W - <u>4.7 %</u>				
4 A	1,380	0.320	442	3,980
B	1,380	0.315	435	
5 A	1,330	0.330	439	4,150
B	1,360	0.328	446	
6 A	1,360	0.321	437	4,350
B	1,270	0.319	405	
		SUM	2,604	12,480
		AVE.	434	4,160
		S.D.	15	
		C.V.	3.4	
<u>4,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>+75° F</u> W - <u> % </u>				
7 A	1,520	0.314	477	5,130
B	1,620	0.326	551	
8 A	1,580	0.322	509	4,170
B	1,680	0.326	548	
9 A	1,580	0.320	506	5,120
B	1,710	0.322	551	
		SUM	3,142	14,420
		AVE.	524	4,810
		S.D.	30	
		C.V.	5.7	

SUMMARY OF STANDARD

CYLINDER TESTS

AGE - 28 DAYS

BATCH	CYL. NO.	ULTIMATE STRENGTH p.s.i.		
		2,000 p.s.i. DESIGN	3,000 p.s.i. DESIGN	4,000 p.s.i. DESIGN
8	1 S	2,390	3,710	5,800
	2 S	2,250	3,640	5,480
	3 S	2,630	3,180	5,590
	SUM	7,270	10,530	16,870
	AVE.	2,420	3,510	5,620
9	1 S	2,010	3,680	5,380
	2 S	2,110	4,070	5,260
	3 S	2,280	3,410	4,710
	SUM	6,400	11,160	15,350
	AVE.	2,130	3,720	5,120
10	1 S	2,420	3,410	4,640
	2 S	2,350	2,790	4,440
	3 S		3,330	4,850
	SUM	4,770	9,530	13,930
	AVE.	2,385	3,180	4,640

SUMMARY OF CYLINDER TESTS

163

BATCH- 1 AGE- 2 MON.
DATE- AUG. 29, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-29°F</u> , W <u>8.1%</u>	
0	0				0	1	7,331
5,000	708	57 1/2	6	9 1/2	0.95	2	7,285
10,000	1,420	138 1/2	-	23	2.33	3	6,875
15,000	2,120	248 1/2	-	41 1/2	4.21	4	7,134
20,000	2,830	382	✓	64	6.40	5	7,186
25,000	3,540	537	✓	90	9.14	6	
30,000	4,250	719	✓	120	12.18	SUM	35,811
35,000	4,960	939	-	156	15.83	AVE.	7,160
40,000	5,670	1,188	✓	198	20.10	S.D.	160
45,000	6,370	1,239	5	248	25.15	C.V.	2.2
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-30°F</u> , W <u>7.0%</u>	
0	0				0	7	8,700
5,000	708	60 1/2	6	10	1.01	8	8,799
10,000	1,420	145 1/2	✓	24	2.44	9	8,882
15,000	2,120	243	✓	40 1/2	4.11	10	9,421
20,000	2,830	305 1/2	5	61	6.19	11	8,973
25,000	3,540	500	6	83	8.42	12	8,940
30,000	4,250	644	-	107	10.86	SUM	53,715
35,000	4,960	809	-	135	13.70	AVE.	8,950
40,000	5,670	993	✓	165 1/2	16.80	S.D.	250
45,000	6,370	1,203	-	201	20.40	C.V.	2.8
50,000	7,080	1,425	-	237	24.03		
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>-31°F</u> , W <u>4.9%</u>	
0	0				0	13	10,277
5,000	708	48	6	8	0.80	14	10,113
10,000	1,420	124 1/2	6	21	2.13	15	10,660
15,000	2,120	182	5	36	3.76	16	10,987
20,000	2,830	332	6	55	5.58	17	10,299
25,000	3,540	454 1/2	✓	76	7.71	18	10,157
30,000	4,250	579	✓	96	9.74	SUM	62,493
35,000	4,960	727	✓	121	12.28	AVE.	10,420
40,000	5,670	749	5	150	15.23	S.D.	330
45,000	6,370	1,039	6	173	17.56	C.V.	3.2
50,000	7,080	1,190	✓	198	20.20		
55,000	7,790	1,344	✓	226	22.94		

SUMMARY OF BEAM TESTS

 BATCH - 1 AGE - 2 MON.

 DATE - AUG. 29, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
2,000 p.s.i. DESIGN				
BEAM TEMP. - -29°F				
W - 6.8%				
1 A	5,250	0.321	1,690	3,000
B	5,030	0.326	1,640	
2 A	5,300	0.321	1,700	2,690
B	5,200	0.319	1,660	
3 A	5,130	0.327	1,680	2,850
B	4,850	0.320	1,550	
		SUM	9,920	8,540
		AVE.	1,650	2,840
		S.D.	55	
		C.V.	3.3	
3,000 p.s.i. DESIGN				
BEAM TEMP. - -25°F				
W - _____%				
4 A	4,800	0.319	1,530	4,070
B	4,750	0.320	1,520	
5 A	4,670	0.330	1,540	
B	5,450	0.331		
6 A	4,530	0.330	1,490	4,470
B	4,570	0.329	1,500	
		SUM	6,040	8,540
		AVE.	1,520	4,270
		S.D.	18	
		C.V.	1.2	
4,000 p.s.i. DESIGN				
BEAM TEMP. - -28°F				
W - _____%				
7 A	4,530	0.318	1,440	4,940
B	4,320	0.325	1,400	
8 A	4,800	0.331	1,590	5,670
B	4,000	0.327	1,310	
9 A	4,230	0.327	1,380	5,360
B	4,540	0.327	1,480	
		SUM	8,600	15,970
		AVE.	1,430	5,320
		S.D.	96	
		C.V.	6.7	

SUMMARY OF CYLINDER TESTS

165

BATCH- 9 AGE- 2 MON.
DATE- OCT 14, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. -16°F, W 7.4%	
0	0				0	1	6,666
4,000	567	38 1/2	6	6 1/2	0.65	2	6,629
8,000	1,130	110	-	18	1.83	3	7,022
12,000	1,700	197 1/2	-	33	3.35	4	6,736
16,000	2,270	293 1/2	-	49	4.97	5	7,193
20,000	2,830	407 1/2	-	68	6.90	6	6,652
24,000	3,400	439	5	88	8.93	SUM	40,898
28,000	3,970	555	5	110	11.17	AVE.	6,820
32,000	4,530	818	6	136	13.80	S.D.	230
36,000	5,180	825	5	165	16.75	C.V.	3.4
3,000 p.s.i. DESIGN						Cylinder Temp. -16°F, W 6.9%	
0	0				0	7	8,047
5,000	708	61	6	10	1.01	8	6,375
10,000	1,420	155	-	26	2.64	9	8,516
15,000	2,120	258	-	43	4.36	10	8,546
20,000	2,830	379	-	63	6.39	11	8,191
25,000	3,540	512 1/2	-	85	8.63	12	7,929
30,000	4,250	658 1/2	-	109	11.06	SUM	41,229
35,000	4,960	821 1/2	-	137	13.91	AVE.	8,250
40,000	5,670	1,011	-	168	17.05	S.D.	280
45,000	6,370	954	5	191	19.39	C.V.	3.4
4,000 p.s.i. DESIGN						Cylinder Temp. -16°F, W 7.3%	
0	0				0	13	8,854
5,000	708	47	6	9 1/2	0.95	14	9,314
10,000	1,420	116	-	23	2.33	15	10,058
15,000	2,120	195	-	39	3.96	16	9,681
20,000	2,830	208 1/2	-	56	5.68	17	9,266
25,000	3,540	369	-	74	7.51	18	10,396
30,000	4,250	459	-	92	9.34	SUM	57,569
35,000	4,960	556 1/2	-	111	11.27	AVE.	9,590
40,000	5,670	666	-	133	13.50	S.D.	570
45,000	6,370	607	4	152	15.43	C.V.	5.9

SUMMARY OF BEAM TESTS

BATCH - 9 AGE - 2 MON.

DATE - OCT. 14, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				
BEAM TEMP. - -16°F				
W - 7.6%				
1 A	4,980	0.322	1,600	2,190
B	4,710	0.328	1,540	
2 A	5,440	0.319	1,740	2,310
B	4,670	0.327	1,530	
3 A	4,530	0.326	1,480	2,390
B	4,640	0.313	1,450	
		SUM	9,340	6,890
		AVE.	1,560	2,300
		S.D.	1.00	
		C.V.	6.6	
3,000 p.s.i. DESIGN				
BEAM TEMP. - -15°F				
W - 6.5%				
4 A	4,630	0.329	1,520	3,680
B	5,130	0.326	1,670	
5 A	3,800	0.320	1,220	3,400
B	3,950	0.321	1,270	
6 A	4,280	0.327	1,400	3,990
B	4,530	0.317	1,440	
		SUM	8,520	11,070
		AVE.	1,420	3,690
		S.D.	180	
		C.V.	12.7	
4,000 p.s.i. DESIGN				
BEAM TEMP. - -11°F				
W - %				
7 A	4,670	0.324	1,510	4,600
B	3,750	0.337	1,260	
8 A	5,200	0.321	1,670	4,950
B	4,050	0.315	1,280	
9 A	4,360	0.314	1,370	5,280
B	4,180	0.315	1,320	
		SUM	9,410	14,830
		AVE.	1,400	4,940
		S.D.	160	
		C.V.	11.1	

SUMMARY OF CYLINDER TESTS

167

BATCH- 7 AGE- 2 MON.
DATE- SEPT. 27, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u>-1.1%</u>							
						1	3,827
						2	3,983
						3	3,983
						4	3,777
						5	3,883
						6	4,271
						SUM	23,724
						AVE.	3,950
						S.D.	175
						C.V.	4.4
<u>3,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u>0.9%</u>							
						7	6,670
						8	6,175
						9	6,550
						10	6,451
						11	6,309
						12	6,118
						SUM	38,273
						AVE.	6,380
						S.D.	220
						C.V.	3.4
<u>4,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u>1.5%</u>							
						13	8,375
						14	8,813
						15	8,432
						16	8,048
						17	8,531
						18	
						SUM	42,199
						AVE.	8,440
						S.D.	
						C.V.	

SUMMARY OF BEAM TESTS

BATCH - 7 AGE - 2 MON.

DATE - SEPT. 27, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN BEAM TEMP. - -18°F W - 0.16 %				
1 A	1,690	0.318	537	2,050
B	1,530	0.316	483	
2 A	1,520	0.321	488	2,490
B	1,570	0.324	509	
3 A	1,700	0.317	539	2,190
B	1,860	0.324	603	
		SUM	3,159	6,730
		AVE.	527	2,240
		S.D.	44	
		C.V.	8.4	
3,000 p.s.i. DESIGN BEAM TEMP. - -18°F W - 0.16 %				
4 A	2,480	0.322	799	3,890
B	2,240	0.326	730	
5 A	2,230	0.330	736	3,780
B	2,500	0.338	845	
6 A	2,650	0.319	845	3,360
B	2,520	0.314	791	
		SUM	4,746	11,030
		AVE.	791	3,680
		S.D.	50	
		C.V.	6.4	
4,000 p.s.i. DESIGN BEAM TEMP. - -18°F W - 0.19 %				
7 A	2,530	0.327	827	4,520
B	2,450	0.339	831	
8 A	2,940	0.326	958	4,830
B	2,350	0.322	757	
9 A	2,630	0.324	852	5,150
B	2,300	0.322	741	
		SUM	4,966	14,500
		AVE.	828	4,830
		S.D.	78	
		C.V.	9.4	

SUMMARY OF CYLINDER TESTS

169

BATCH- 2 AGE- 2 MON.
DATE- AUG. 31, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. - <u>1</u> °F, W <u>6.6</u> %	
0	0				0	1	5,983
5,000	708	40 1/2	4	10	1.01	2	5,437
10,000	1,420	100	✓	25	2.54	3	5,761
15,000	2,120	170	✓	42 1/2	4.31	4	5,825
20,000	2,830	248	✓	62	6.29	5	
25,000	3,540	339 1/2	✓	85	8.63	6	
30,000	4,250	322	3	107	10.86	SUM	23,006
						AVE.	5,750
						S.D.	
						C.V.	
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. - <u>2</u> °F, W <u>6.2</u> %	
0	0				0	7	7,225
5,000	708	55 1/2	5	11	1.12	8	7,466
10,000	1,420	148 1/2	6	25	2.54	9	7,777
15,000	2,120	247 1/2	✓	41	4.16	10	7,651
20,000	2,830	358	✓	59 1/2	6.04	11	8,019
25,000	3,540	310 1/2	4	77 1/2	7.87	12	7,681
30,000	4,250	599	6	100	10.15	SUM	45,819
35,000	4,960	733 1/2	✓	122	12.38	AVE.	7,640
40,000	5,670	737 1/2	5	147 1/2	14.97	S.D.	270
45,000	6,370	1,087	6	181	18.37	C.V.	3.6
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp - <u>2</u> °F, W <u>6.0</u> %	
0	0				0	13	9,412
5,000	708	55 1/2	5	11	1.12	14	9,028
10,000	1,420	118	✓	24	2.44	15	9,358
15,000	2,120	190 1/2	✓	38	3.86	16	9,195
20,000	2,830	271 1/2	✓	54	5.48	17	9,600
25,000	3,540	357	✓	71	7.21	18	9,732
30,000	4,250	446 1/2	✓	89	9.03	SUM	56,325
35,000	4,960	540 1/2	✓	108	10.96	AVE.	9,390
40,000	5,670	645	✓	129	13.09	S.D.	260
45,000	6,370	759	✓	152	15.43	C.V.	2.7
50,000	7,080	885 1/2	✓	177	17.97		
55,000	7,790	591	3	197	20.00		

SUMMARY OF BEAM TESTS

BATCH - 2 AGE - 2 MON.

DATE - AUG. 31, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				
BEAM TEMP. - <u>-1</u> °F				
W - <u>6.5</u> %				
1 A	5,040	0.315	1,590	2,450
B	4,540	0.317	1,440	
2 A	4,930	0.320	1,580	2,320
B	4,390	0.321	1,410	
3 A	4,770	0.323	1,540	2,090
B	4,730	0.328	1,550	
		SUM	9,110	6,860
		AVE.	1,520	2,290
		S.D.	75	
		C.V.	4.9	
3,000 p.s.i. DESIGN				
BEAM TEMP. - <u>-1</u> °F				
W - <u>6.0</u> %				
4 A	4,050	0.327	1,320	4,280
B	4,590	0.320	1,470	
5 A	5,040	0.328	1,650	3,140
B	4,610	0.324	1,490	
6 A	4,600	0.324	1,490	3,630
B	4,400	0.326	1,430	
		SUM	8,850	11,050
		AVE.	1,475	3,680
		S.D.	110	
		C.V.	7.2	
4,000 p.s.i. DESIGN				
BEAM TEMP. - <u>0</u> °F				
W - <u>5.6</u> %				
7 A	4,780	0.320	1,530	4,320
B	4,600	0.323	1,490	
8 A	4,760	0.323	1,540	4,300
B	4,100	0.325	1,330	
9 A				
B				
		SUM	5,890	
		AVE.	1,470	4,310
		S.D.		
		C.V.		

SUMMARY OF CYLINDER TESTS

171

BATCH- 8 AGE- 2 MON.
DATE- OCT. 13, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. $+14^{\circ}\text{F}$, W <u>7.4%</u>	
0	0				0	1	4,814
4,000	567	56 1/2	6	9 1/2	0.95	2	4,900
8,000	1,130	143	-	24	2.44	3	4,541
12,000	1,700	246	-	41	4.16	4	5,131
16,000	2,270	371	-	62	6.29	5	5,380
20,000	2,830	513	-	85 1/2	8.68	6	5,199
24,000	3,400	569	5	114	11.57	SUM	29,965
28,000	3,970	907	6	151	15.33	AVE.	4,990
						S.D.	300
						C.V.	6.1
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. $+13^{\circ}\text{F}$, W <u>7.1%</u>	
0	0				0	7	6,295
5,000	708	66 1/2	5	13	1.32	8	6,580
10,000	1,420	153	-	31	3.15	9	6,808
15,000	2,120	252 1/2	-	50 1/2	5.13	10	6,417
20,000	2,830	364	-	73	7.41	11	6,609
25,000	3,540	297	3	99	10.05	12	6,151
30,000	4,250	612	5	122	12.38	SUM	38,860
35,000	4,960	771 1/2	-	154	15.63	AVE.	6,480
						S.D.	240
						C.V.	3.7
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. $+14^{\circ}\text{F}$, W <u>6.6%</u>	
0	0				0	13	8,044
5,000	708	68 1/2	6	11 1/2	1.17	14	8,063
10,000	1,420	163 1/2	-	27	2.74	15	8,488
15,000	2,120	272	-	45	4.57	16	8,202
20,000	2,830	389	-	65	6.50	17	8,603
25,000	3,540	417	5	83	8.42	18	8,134
30,000	4,250	530	-	106	10.76	SUM	49,534
35,000	4,960	630	-	126	12.79	AVE.	8,255
40,000	5,670	904	6	151	15.33	S.D.	210
45,000	6,370	1060	-	177	17.97	C.V.	2.6

SUMMARY OF BEAM TESTS

BATCH - 8 AGE - 2 MON.

DATE - OCT 13, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+14^{\circ}\text{F}$				
W - 7.0 %				
1 A	3,940	0.325	1,280	2,840
B	4,540	0.328	1,490	
2 A	3,870	0.329	1,270	2,840
B	3,940	0.328	1,290	
3 A	3,810	0.314	1,200	2,660
B	3,580	0.315	1,130	
SUM			7,660	8,340
AVE.			1,280	2,780
S.D.			120	
C.V.			9.5	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+15^{\circ}\text{F}$				
W - 6.9 %				
4 A	3,520	0.346	1,220	3,190
B	3,320	0.330	1,100	
5 A	4,050	0.330	1,370	3,930
B	3,430	0.326	1,120	
6 A	3,630	0.328	1,190	3,930
B	3,320	0.319	1,060	
SUM			7,060	11,050
AVE.			1,180	3,680
S.D.			110	
C.V.			9.7	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+15^{\circ}\text{F}$				
W - 6.2 %				
7 A	4,100	0.309	1,270	4,620
B	4,050	0.311	1,260	
8 A	4,070	0.325	1,320	4,750
B	4,410	0.333	1,470	
9 A	3,700	0.330	1,220	3,980
B	3,580	0.331	1,180	
SUM			7,720	13,350
AVE.			1,290	4,450
S.D.			100	
C.V.			7.9	

SUMMARY OF CYLINDER TESTS

173

BATCH- 3 AGE- 2 MON.
DATE- SEPT. 2, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+34°F</u> ; W <u>8.1%</u>	
0	0				0	1	2,530
3,000	425	52 1/2	6	8 1/2	0.85	2	2,825
6,000	850	128	-	21	2.13	3	2,879
9,000	1,275	238 1/2	-	39 1/2	4.01	4	2,971
12,000	1,700	377	-	63	6.39	5	2,780
15,000	2,120	561	-	93	9.44	6	2,716
18,000	2,550	706	5	141	14.31	SUM	16,701
						AVE.	2,780
						S.D.	150
						C.V.	5.5
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+34°F</u> , W <u>6.3%</u>	
0	0				0	7	4,279
3,000	425	50 1/2	6	8 1/2	0.85	8	3,834
6,000	850	114 1/2	-	19	1.93	9	3,669
9,000	1,275	189 1/2	-	31 1/2	3.20	10	3,749
12,000	1,700	267	-	44 1/2	4.52	11	3,933
15,000	2,120	356	-	59	5.99	12	3,904
18,000	2,550	457	-	76	7.71	SUM	23,368
21,000	2,970	579	-	96 1/2	9.79	AVE.	3,890
24,000	3,400	587	5	117	11.88	S.D.	210
						C.V.	5.5
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+34°F</u> , W <u>5.8%</u>	
0	0				0	13	5,079
4,000	567	65 1/2	6	11	1.12	14	5,089
8,000	1,130	152	-	25	2.54	15	6,012
12,000	1,700	248	-	41	4.16	16	5,706
16,000	2,270	286	5	57	5.79	17	5,545
20,000	2,830	444 1/2	6	74	7.51	18	5,821
24,000	3,400	556 1/2	6	93	9.44	SUM	33,252
28,000	3,970	428	4	107	10.86	AVE.	5,540
32,000	4,530	546	4	136	13.80	S.D.	380
						C.V.	7.0

SUMMARY OF BEAM TESTS

BATCH - 3 AGE - 2 MON.

DATE - SEPT. 2, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+34^{\circ}\text{F}$				
W - <u>6.8%</u>				
1 A	1,230	0.322	396	2,970
B	930	0.326	303	
2 A	1,000	0.324	324	2,790
B	980	0.314	308	
3 A	880	0.321	282	2,320
B	750	0.320	240	
		SUM	1,853	8,080
		AVE.	309	2,690
		S.D.	51	
		C.V.	16.6	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+34^{\circ}\text{F}$				
W - <u>6.3%</u>				
4 A	1,310	0.331	434	3,850
B	1,370	0.332	455	
5 A	890	0.324		3,290
B	1,230	0.326	401	
6 A	1,370	0.320	438	3,480
B	1,230	0.320	394	
		SUM	2,120	10,620
		AVE.	424	3,540
		S.D.	26	
		C.V.	6.1	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $+34^{\circ}\text{F}$				
W - <u>5.8%</u>				
7 A	1,360	0.316	0.430	4,560
B	1,320	0.333	0.440	
8 A	1,350	0.321	0.433	4,560
B	1,580	0.322	0.509	
9 A	1,380	0.328	0.453	5,270
B	1,480	0.330	0.488	
		SUM	2,753	14,390
		AVE.	459	4,800
		S.D.	32	
		C.V.	7.1	

SUMMARY OF CYLINDER TESTS

175

BATCH- 10 AGE- 2 MON.
DATE- Nov. 5, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u>6.4%</u>	
0	0				0	1	2,934
3,000	425	62	5	12 1/2	1.27	2	2,773
6,000	850	144	-	29	2.94	3	3,056
9,000	1,275	251	-	50	5.08	4	2,706
12,000	1,700	381	-	76	7.71	5	2,815
15,000	2,120	539 1/2	-	108	10.96	6	
18,000	2,550	627	4	158	16.04	SUM	14,284
						AVE.	2,860
						S.D.	140
						C.V.	4.7
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u>6.6%</u>	
0	0				0	7	4,116
3,000	425	69	6	11 1/2	1.17	8	4,216
6,000	850	159 1/2	-	26 1/2	2.69	9	4,060
9,000	1,275	255 1/2	-	42 1/2	4.31	10	4,202
12,000	1,700	358	-	59 1/2	6.04	11	4,287
15,000	2,120	398	5	80	8.12	12	4,499
18,000	2,550	592	6	99	10.05	SUM	25,380
21,000	2,970	741	-	123	12.48	AVE.	4,230
24,000	3,400	909	-	152	15.43	S.D.	220
						C.V.	6.1
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u>6.3%</u>	
0	0				0	13	5,597
4,000	567	55 1/2	4	11	1.12	14	5,205
8,000	1,133	176	6	29	2.94	15	4,519
12,000	1,700	307 1/2	-	51	5.18	16	5,783
16,000	2,270	420 1/2	-	70	7.11	17	4,996
20,000	2,830	470 1/2	5	94	9.54	18	5,347
24,000	3,400	702	6	117	11.88	SUM	31,447
28,000	3,970	867 1/2	6	144	14.62	AVE.	5,240
32,000	4,530	857	5	171	17.36	S.D.	450
						C.V.	8.6

SUMMARY OF BEAM TESTS

 BATCH - 10 AGE - 2 MON.

 DATE - Nov. 5, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN BEAM TEMP. - <u>+49° F</u> W - <u>6.3%</u>				
1 A	930	0.324	301	2,740
B	860	0.325	280	
2 A				
B				
3 A	860	0.313	269	2,670
B	880	0.332	292	
		SUM	1,142	5,410
		AVE.	285	2,705
		S.D.		
		C.V.		
3,000 p.s.i. DESIGN BEAM TEMP. - <u>+49° F</u> W - <u>5.8%</u>				
4 A	955	0.309	295	3,220
B	760	0.318	242	
5 A	830	0.327	271	3,340
B	880	0.328	289	
6 A	690	0.328	226	3,680
B	980	0.332	325	
		SUM	1,648	10,240
		AVE.	275	3,410
		S.D.	36	
		C.V.	13.1	
4,000 p.s.i. DESIGN BEAM TEMP. - <u>+49° F</u> W - <u>5.7%</u>				
7 A	1,250	0.320	400	4,750
B	1,345	0.322	433	
8 A	1,395	0.321	448	4,170
B	1,445	0.318	459	
9 A	1,110	0.315	350	4,650
B	1,000	0.317	317	
		SUM	2,407	13,570
		AVE.	401	4,520
		S.D.	57	
		C.V.	14.2	

SUMMARY OF CYLINDER TESTS

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BATCH- 4 AGE - 2 MON.

DATE - SEPT. 6, 60

STRESS - STRAIN

ULTIMATE

LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. _____°F, W 6.1 %							
0	0				0	1	2,766
3,000	425	45 1/2	4	11	1.12	2	2,484
6,000	850	139 1/2	5	28	2.84	3	2,773
9,000	1,275	242 1/2	-	48 1/2	4.92	4	2,605
12,000	1,700	375 1/2	-	75	7.61	5	2,589
15,000	2,120	559 1/2	-	112	11.37	6	2,735
18,000	2,550	670 1/2	4	168	17.05	SUM	15,252
						AVE.	2,660
						S.D.	120
						C.V.	4.5

3,000 p.s.i. DESIGN Cylinder Temp. _____°F, W 6.1 %							
0	0				0	7	4,555
3,000	425	42	6	8	0.80	8	4,088
6,000	850	118	-	19 1/2	1.98	9	5,086
9,000	1,275	162	5	32	3.25	10	4,506
12,000	1,700	275 1/2	6	46	4.67	11	4,364
15,000	2,120	363 1/2	-	60 1/2	6.14	12	4,554
18,000	2,550	445 1/2	-	74	7.51	SUM	27,153
21,000	2,970	555	-	92 1/2	9.39	AVE.	4,520
24,000	3,400	667 1/2	-	111	11.27	S.D.	330
27,000	3,820	810	-	135	13.70	C.V.	7.2

4,000 p.s.i. DESIGN Cylinder Temp. _____°F, W 6.0 %							
0	0				0	13	5,893
5,000	708	76 1/2	5	15	1.52	14	5,927
10,000	1,420	187	-	37	3.76	15	5,927
15,000	2,120	295 1/2	-	59	5.99	16	4,404
20,000	2,830	415 1/2	-	83	8.42	17	5,871
25,000	3,540	541	-	108	10.96	18	5,545
30,000	4,250	681	-	136	13.80	SUM	34,567
35,000	4,960	843	-	169	17.15	AVE.	5,760
						S.D.	230
						C.V.	4.0

SUMMARY OF BEAM TESTS

 BATCH - 4 AGE - 2 MON.

 DATE - SEPT. 6, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+75° F</u>				
W - <u>6.3%</u>				
1 A	870	0.319	277	2,360
B	1,090	0.312	340	
2 A	660	0.331	218	2,830
B	940	0.316	297	
3 A	845	0.332	280	2,650
B	820	0.322	264	
		SUM	1,676	7,840
		AVE.	279	2,610
		S.D.	40	
		C.V.	14.3	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+75° F</u>				
W - <u>6.0%</u>				
4 A	1,330	0.318	422	3,200
B	1,380	0.320	442	
5 A	1,125	0.319	359	3,790
B	1,290	0.323	417	
6 A	1,410	0.319	450	4,460
B	1,260	0.322	406	
		SUM	2,496	12,150
		AVE.	416	4,050
		S.D.	22	
		C.V.	7.8	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+75° F</u>				
W - <u>5.7%</u>				
7 A	1,450	0.319	462	4,950
B	1,480	0.321	475	
8 A	1,570	0.331	520	4,650
B	1,590	0.331	526	
9 A	1,570	0.321	503	4,830
B	1,570	0.333	523	
		SUM	3,009	14,430
		AVE.	501	4,810
		S.D.	27	
		C.V.	5.4	

SUMMARY OF STANDARD
CYLINDER TESTS

AGE - 2 MON.

BATCH	CYL. NO.	ULTIMATE STRENGTH p.s.i.		
		2,000 p.s.i. DESIGN	3,000 p.s.i. DESIGN	4,000 p.s.i. DESIGN
8	1 S	2,800	3,960	5,560
	2 S	2,910	4,340	6,080
	3 S	2,510	4,530	6,070
	SUM	8,220	12,830	17,710
	AVE.	2,740	4,280	5,900
9	1 S	2,600	4,460	5,650
	2 S	2,440	4,570	6,030
	3 S	2,550	4,660	5,950
	SUM	7,590	13,690	17,630
	AVE.	2,530	4,560	5,880
10	1 S	2,650	3,600	
	2 S	2,680	4,120	4,780
	3 S	2,840	3,970	4,770
	SUM	8,170	11,690	
	AVE.	2,720	3,900	4,775

SUMMARY OF CYLINDER TESTS

180

BATCH- 1 AGE- 4 MON.
DATE- OCT. 1, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. -28°F , W 7.2 %	
0	0				0	1	6,854
5,000	708	46	5	9	0.90	2	7,243
10,000	1,420	115 1/2	✓	23	2.33	3	7,070
15,000	2,120	217 1/2	✓	43 1/2	4.41	4	7,002
20,000	2,830	321 1/2	✓	64	6.40	5	6,903
25,000	3,540	442 1/2	✓	88 1/2	8.98	6	7,399
30,000	4,250	587	✓	117	11.88	SUM	42,471
35,000	4,960	755	✓	151	15.33	AVE.	7,080
40,000	5,670	958	✓	192	19.49	S.D.	210
						C.V.	3.0
3,000 p.s.i. DESIGN						Cylinder Temp. -30°F , W 8.9 %	
0	0				0	7	9,127
5,000	708	45	6	7 1/2	0.75	8	9,421
10,000	1,420	125	✓	21	2.13	9	9,584
15,000	2,120	220	✓	37	3.76	10	9,832
20,000	2,830	326	✓	54	5.48	11	9,803
25,000	3,540	452 1/2	✓	75	7.61	12	8,488
30,000	4,250	586 1/2	✓	98	9.95	SUM	56,255
35,000	4,960	732	✓	122	12.38	AVE.	9,375
40,000	5,670	888	✓	148	15.02	S.D.	500
45,000	6,370	893	5	179	18.17	C.V.	5.4
50,000	7,080	1036	✓	207	21.01		
4,000 p.s.i. DESIGN						Cylinder Temp. -30°F , W 5.9 %	
0	0				0	13	10,284
5,000	708	55	6	9	0.90	14	9,942
10,000	1,420	132 1/2	✓	22	2.23	15	10,007
15,000	2,120	233	✓	39	3.96	16	9,315
20,000	2,830	345	✓	57 1/2	5.84	17	9,113
25,000	3,540	457 1/2	✓	76	7.71	18	10,369
30,000	4,250	575 1/2	✓	96	9.74	SUM	59,030
35,000	4,960	702 1/2	✓	117	11.88	AVE.	9,840
40,000	5,670	833	✓	139	14.11	S.D.	510
45,000	6,370	971	✓	162	16.44	C.V.	5.2
50,000	7,080	1,124	✓	187	18.98		
55,000	7,790	1,276	✓	213	21.62		
60,000	8,500	1,433	✓	278	28.2		

SUMMARY OF BEAM TESTS

BATCH - 1 AGE - 4 MON.
DATE - OCT. 1, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-28</u> °F				
W - <u>6.9</u> %				
1 A	6,230	0.330	2,060	3,250
B	4,650	0.326	1,520	
2 A	6,230	0.325	2,020	2,730
B	5,650	0.324	1,830	
3 A	4,480	0.325	1,450	3,080
B	5,810	0.329	1,910	
SUM			10,790	9,060
AVE.			1,800	3,020
S.D.			260	
C.V.			14.3	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-30</u> °F				
W - <u>5.7</u> %				
4 A	4,650	0.326	1,520	4,520
B	3,980	0.330	1,310	
5 A	5,400	0.328	1,770	4,540
B	4,540	0.324	1,470	
6 A	5,170	0.319	1,650	4,530
B	4,190	0.319	1,370	
SUM			9,090	13,590
AVE.			1,515	4,530
S.D.			170	
C.V.			11.3	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>-29</u> °F				
W - <u>5.1</u> %				
7 A	3,910	0.328	1,280	5,840
B	3,520	0.327	1,150	
8 A	3,770	0.326	1,230	5,240
B	3,810	0.328	1,250	
9 A	4,040	0.332	1,340	5,800
B	4,800	0.327	1,570	
SUM			7,820	17,580
AVE.			1,300	5,860
S.D.			145	
C.V.			11.1	

SUMMARY OF CYLINDER TESTS

182

BATCH- 9 AGE- 4 MON.
DATE- DEC 7, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. -17 °F, W %	
0	0				0	1	6,431
5,000	708	56	6	9 1/2	0.95	2	6,865
10,000	1,420	148 1/2	✓	25	2.54	3	6,274
15,000	2,120	263 1/2	✓	44	4.47	4	6,780
20,000	2,830	394 1/2	✓	66	6.60	5	6,620
25,000	3,540	557	✓	93	9.44	6	6,267
30,000	4,250	714	✓	119	12.08	SUM	39,240
35,000	4,960	909	✓	151	15.33	AVE.	6,540
40,000	5,670	1,154	✓	192	19.49	S.D.	260
						C.V.	3.9
3,000 p.s.i. DESIGN						Cylinder Temp. -17 °F, W %	
0	0				0	7	
5,000	708	53	6	9	0.90	8	8,431
10,000	1,420	130	✓	22	2.23	9	8,942
15,000	2,120	220	✓	37	3.76	10	9,229
20,000	2,830	320 1/2	✓	53 1/2	5.43	11	8,289
25,000	3,540	426 1/2	✓	71	7.21	12	9,429
30,000	4,250	544 1/2	✓	91	9.24	SUM	44,320
35,000	4,960	671	✓	112	11.37	AVE.	8,860
40,000	5,670	810 1/2	✓	135	13.70	S.D.	490
45,000	6,370	968 1/2	✓	161	16.34	C.V.	5.5
50,000	7,080	1,159	✓	193	19.59		
55,000	7,790	902	4	225	22.84		
4,000 p.s.i. DESIGN						Cylinder Temp. -17 °F, W %	
0	0				0	13	10,376
5,000	708	49	6	8	0.80	14	10,505
10,000	1,420	129 1/2	✓	21 1/2	2.18	15	9,605
15,000	2,120	218 1/2	✓	36 1/2	3.70	16	10,121
20,000	2,830	313 1/2	✓	52	5.28	17	9,756
25,000	3,540	412	✓	69	7.00	18	9,510
30,000	4,250	519	✓	86	8.73	SUM	59,873
35,000	4,960	630	✓	105	10.66	AVE.	9,980
40,000	5,670	748 1/2	✓	125	12.69	S.D.	420
45,000	6,370	871	✓	145	14.72	C.V.	4.2
50,000	7,080	1,007	✓	168	17.05		
55,000	7,790	1,142 1/2	✓	190	19.29		

SUMMARY OF BEAM TESTS

183

BATCH - 9 AGE - 4 MON.

DATE - DEC. 7, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
2,000 p.s.i. DESIGN				
BEAM TEMP. - -17°F				
W - 7.3 %				
1 A				2,570
B	4,490	0.319	1,430	
2 A				
B				
3 A	4,500	0.329	1,480	2,430
B	4,300	0.340	1,460	
		SUM		5,000
		AVE.	1,460	2,500
		S.D.		
		C.V.		
3,000 p.s.i. DESIGN				
BEAM TEMP. - -15°F				
W - 6.2 %				
4 A	4,480	0.316	1,420	4,100
B	5,040	0.315	1,590	
5 A	4,300	0.317	1,360	4,160
B				
6 A	4,370	0.312	1,360	3,690
B	4,770	0.324	1,550	
		SUM	7,280	11,950
		AVE.	1,460	3,980
		S.D.	110	
		C.V.	7.4	
4,000 p.s.i. DESIGN				
BEAM TEMP. - -13°F				
W - 6.4 %				
7 A	4,400	0.319	1,400	5,300
B	4,360	0.325	1,420	
8 A	4,700	0.309	1,450	5,550
B	4,900	0.307	1,500	
9 A	4,250	0.310	1,320	5,250
B	4,180	0.314	1,310	
		SUM	8,400	16,100
		AVE.	1,400	5,370
		S.D.	74	
		C.V.	5.3	

SUMMARY OF CYLINDER TESTS 184

BATCH- 7 AGE- 4 MON.
DATE- Nov. 19, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RD'G.	AVE. DIAL RD'G.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u>2.8%</u>							
						1	6,231
						2	6,502
						3	6,253
						4	5,927
						5	5,885
						6	6,536
						SUM	37,334
						AVE.	6,220
						S.D.	280
						C.V.	4.4
<u>3,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-18°F</u> , W <u>5.7%</u>							
						7	7,437
						8	8,120
						9	8,134
						10	8,786
						11	7,257
						12	7,579
						SUM	47,313
						AVE.	7,885
						S.D.	570
						C.V.	7.2
<u>4,000 p.s.i. DESIGN</u> Cylinder Temp. <u>-17°F</u> , W <u>5.5%</u>							
						13	8,358
						14	9,054
						15	9,563
						16	10,313
						17	
						18	
						SUM	37,288
						AVE.	9,320
						S.D.	
						C.V.	

SUMMARY OF BEAM TESTS

BATCH - 7 AGE - 4 MON.
DATE - Nov. 19, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
2,000 p.s.i. DESIGN BEAM TEMP. - <u>-18</u> °F W - <u>2.4</u> %				
1 A	3,150	0.317	999	2,820
B	3,270	0.318	1,040	
2 A	2,450	0.318	779	2,350
B	2,970	0.333	989	
3 A	3,130	0.324	1,014	2,580
B	3,450	0.326	1,125	
		SUM	5,946	7,750
		AVE.	991	2,580
		S.D.	110	
		C.V.	11.6	
3,000 p.s.i. DESIGN BEAM TEMP. - <u>-18</u> °F W - <u>5.0</u> %				
4 A	3,270	0.333	1,089	4,310
B	2,580	0.331	854	
5 A	3,280	0.320	1,050	4,080
B	3,230	0.318	1,027	
6 A	2,720	0.339	922	4,860
B	2,850	0.328	935	
		SUM	5,877	13,250
		AVE.	980	4,420
		S.D.	110	
		C.V.	11.0	
4,000 p.s.i. DESIGN BEAM TEMP. - <u>-18</u> °F W - <u>5.6</u> %				
7 A	2,550	0.325	829	5,280
B	2,820	0.328	925	
8 A	2,700	0.327	883	5,420
B	3,220	0.327	1,053	
9 A	2,760	0.326	900	5,220
B	3,010	0.330	993	
		SUM	5,583	15,920
		AVE.	930	5,310
		S.D.	80	
		C.V.	8.6	

SUMMARY OF CYLINDER TESTS

186

BATCH- 2 AGE- 4 MON.
DATE- OCT. 24, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. - <u>1</u> °F, W <u>6.7</u> %	
0	0				0	1	6,323
5,000	708	62 1/2	6	10 1/2	1.06	2	6,502
10,000	1,420	149 1/2	-	25	2.54	3	5,555
15,000	2,120	249	-	41	4.21	4	5,256
20,000	2,830	364	-	61	6.19	5	6,290
25,000	3,540	493 1/2	-	82	8.32	6	5,911
30,000	4,250	653	-	109	11.06	SUM	35,837
35,000	4,960	773	-	128	13.00	AVE.	5,970
40,000	5,670	704	4	176	17.86	S.D.	520
						C.V.	8.8
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. - <u>1</u> °F, W <u>6.3</u> %	
0	0				0	7	7,964
5,000	708	54 1/2	5	11	1.12	8	8,218
10,000	1,420	122 1/2	-	24 1/2	2.49	9	8,162
15,000	2,120	201 1/2	-	40	4.06	10	7,625
20,000	2,830	288 1/2	-	58	5.89	11	7,933
25,000	3,540	383	-	76 1/2	7.76	12	8,233
30,000	4,250	486 1/2	-	97	9.85	SUM	48,135
35,000	4,960	595 1/2	-	119	12.08	AVE.	8,020
40,000	5,670	578 1/2	4	144	14.62	S.D.	210
45,000	6,370	678 1/2	4	169	17.15	C.V.	2.6
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. - <u>1</u> °F, W <u>6.1</u> %	
0	0				0	13	9,144
5,000	708	48 1/2	5	9 1/2	0.95	14	9,562
10,000	1,420	113	-	23	2.33	15	9,439
15,000	2,120	185 1/2	-	37	3.76	16	9,407
20,000	2,830	265	-	53	5.38	17	8,884
25,000	3,540	346 1/2	-	69	7.00	18	8,902
30,000	4,250	345 1/2	4	86	8.73	SUM	55,338
35,000	4,960	538	5	107	10.86	AVE.	9,220
40,000	5,670	641 1/2	-	128	12.99	S.D.	290
45,000	6,370	754 1/2	-	151	15.33	C.V.	3.2
50,000	7,080	706 1/2	4	177	17.97		

SUMMARY OF BEAM TESTS

BATCH - 2 AGE - 4 MON.

DATE - OCT. 24, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>-1</u> °F W - <u>7.1</u> %				
1 A	4,580	0.327	1,500	2,880
B	4,970	0.330	1,640	
2 A	4,120	0.326	1,340	3,180
B	5,820	0.321	1,870	
3 A	4,430	0.325	1,440	2,800
B	4,600	0.324	1,490	
SUM			9,280	8,860
AVE.			1,550	2,950
S.D.			170	
C.V.			11.0	
<u>3,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>-1</u> °F W - <u>6.2</u> %				
4 A	4,540	0.334	1,520	4,900
B	4,910	0.327	1,610	
5 A	5,340	0.333	1,780	4,910
B	4,710	0.337	1,590	
6 A	5,610	0.330	1,850	4,770
B	4,880	0.325	1,590	
SUM			9,940	14,580
AVE.			1,660	4,860
S.D.			130	
C.V.			7.6	
<u>4,000 p.s.i. DESIGN</u> BEAM TEMP. - <u>-1</u> °F W - <u>5.9</u> %				
7 A	5,170	0.332	1,720	5,600
B	4,550	0.327	1,490	
8 A	4,530	0.332	1,460	5,200
B	4,800	0.327	1,570	
9 A				5,710
B	4,960	0.320	1,590	
SUM			7,830	16,510
AVE.			1,570	5,500
S.D.			100	
C.V.			6.5	

SUMMARY OF CYLINDER TESTS

188

BATCH- 8 AGE- 4 MON.
DATE- DEC. 6, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RD'G'S.	NO. of RD'G.	AVE. DIAL RD'G.	UNIT STRAIN x 10 ⁻⁴	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 15^{\circ}\text{F}$, W <u>7.6%</u>	
0	0					1	4,933
4,000	567	53	6	9	0.90	2	4,810
8,000	1,130	135 1/2	-	22 1/2	2.28	3	5,096
12,000	1,700	239 1/2	-	40	4.06	4	4,572
16,000	2,270	353	-	59	5.99	5	5,082
20,000	2,830	488 1/2	-	81 1/2	8.26	6	5,004
24,000	3,400	644	-	107	10.86	SUM	29,497
28,000	3,970	842 1/2	-	140	14.21	AVE.	4,920
32,000	4,530	707 1/2	4	177	17.97	S.D.	240
						C.V.	4.8
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 15^{\circ}\text{F}$, W <u>7.4%</u>	
0	0					7	6,438
5,000	708	68	6	11 1/2	1.17	8	5,974
10,000	1,420	139	-	23	2.33	9	6,460
15,000	2,120	279	-	47	4.77	10	5,982
20,000	2,830	401	-	67	6.80	11	6,466
25,000	3,540	544 1/2	-	91	9.24	12	6,765
30,000	4,250	713 1/2	-	117	11.88	SUM	38,085
35,000	4,960	916 1/2	-	153	15.53	AVE.	6,350
40,000	5,670	1183	-	197	20.00	S.D.	310
						C.V.	4.9
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. $\pm 14^{\circ}\text{F}$, W <u>6.6%</u>	
0	0					13	8,047
5,000	708	48	5	9 1/2	0.95	14	7,537
10,000	1,420	147 1/2	6	24 1/2	2.49	15	7,720
15,000	2,120	252	-	42	4.26	16	7,648
20,000	2,830	365 1/2	-	61	6.19	17	7,235
25,000	3,540	487 1/2	-	81	8.21	18	8,078
30,000	4,250	615 1/2	-	102	10.35	SUM	46,265
35,000	4,960	754	-	126	12.79	AVE.	7,710
40,000	5,670	907	-	151	15.33	S.D.	320
45,000	6,370	1,080 1/2	-	180	18.27	C.V.	4.1
50,000	7,080	1,117	5	223	22.63		

SUMMARY OF BEAM TESTS

 BATCH - 8 AGE - 4 MON.

 DATE - DEC. 6, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $\pm 12^{\circ}\text{F}$				
W - 6.9%				
1 A	4,580	0.331	1,520	2,850
B	4,120	0.320	1,320	
2 A				3,040
B	4,150	0.326	1,350	
3 A	4,530	0.315	1,430	2,870
B	4,250	0.318	1,350	
		SUM	6,970	8,760
		AVE.	1,390	2,920
		S.D.	73	
		C.V.	5.2	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $\pm 15^{\circ}\text{F}$				
W - 7.3%				
4 A	4,220	0.322	1,360	4,050
B	4,220	0.314	1,330	
5 A	3,870	0.326	1,260	4,040
B	3,950	0.335	1,320	
6 A	4,120	0.327	1,350	4,120
B	4,370	0.327	1,430	
		SUM	8,050	12,210
		AVE.	1,340	4,070
		S.D.	56	
		C.V.	4.2	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - $\pm 17^{\circ}\text{F}$				
W - 6.2%				
7 A	3,850	0.312	1,200	6,000
B	4,460	0.313	1,400	
8 A	3,700	0.318	1,180	5,320
B	3,930	0.322	1,270	
9 A	2,960	0.344	1,020	6,200
B	3,400	0.350	1,190	
		SUM	7,260	17,520
		AVE.	1,210	5,840
		S.D.	420	
		C.V.	10.3	

SUMMARY OF CYLINDER TESTS

190

BATCH- 3 AGE- 4 MON.
DATE- OCT. 29, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN Cylinder Temp. $+31^{\circ}\text{F}$, W 6.4%							
0	0				0	1	2,992
3,000	425	55	5	11	1.12	2	2,985
6,000	850	123	✓	25	2.54	3	3,155
9,000	1,275	207	✓	41	4.16	4	3,059
12,000	1,700	313	✓	63	6.39	5	3,247
15,000	2,120	447	✓	89	9.03	6	3,282
18,000	2,550	497	4	124	12.59	SUM	18,820
						AVE.	3,140
						S.D.	130
						C.V.	4.1
3,000 p.s.i. DESIGN Cylinder Temp. $+31^{\circ}\text{F}$, W 6.3%							
0	0				0	7	4,428
4,000	567	66 1/2	6	11	1.12	8	4,484
8,000	1,130	164	✓	27	2.74	9	4,711
12,000	1,700	261 1/2	✓	43 1/2	4.41	10	4,729
16,000	2,270	388	✓	65	6.50	11	4,272
20,000	2,830	525	✓	87 1/2	8.88	12	3,819
24,000	3,400	578	✓	116	11.77	SUM	26,443
28,000	3,970	600	4	150	15.23	AVE.	4,410
						S.D.	340
						C.V.	7.6
4,000 p.s.i. DESIGN Cylinder Temp. $+31^{\circ}\text{F}$, W 6.4%							
0	0				0	13	6,538
4,000	567	63 1/2	6	10 1/2	1.06	14	5,776
8,000	1,130	116	5	23	2.33	15	6,012
12,000	1,700	230 1/2	6	38	3.86	16	5,531
16,000	2,270	330	✓	55	5.58	17	5,347
20,000	2,830	432 1/2	✓	72	7.31	18	5,284
24,000	3,400	461 1/2	5	92	9.34	SUM	35,178
28,000	3,970	670	6	112	11.37	AVE.	5,860
32,000	4,530	806 1/2	✓	134	13.60	S.D.	420
36,000	5,100	821	5	164	16.65	C.V.	7.2

SUMMARY OF BEAM TESTS

 BATCH - 3 AGE - 4 MON.

 DATE - OCT 29, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	psi
<u>2,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+31</u> °F				
W - <u>7.0</u> %				
1 A	1,320	0.316	417	2,530
B				
2 A	1,075	0.326	350	3,120
B	940	0.322	303	
3 A	890	0.317	282	2,920
B	1,110	0.325	361	
SUM			1,713	8,570
AVE.			343	2,860
S.D.			50	
C.V.			14.5	
<u>3,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+31</u> °F				
W - <u>6.7</u> %				
4 A	1,430	0.321	459	4,550
B				
5 A	1,445	0.325	470	4,300
B	1,160	0.325	377	
6 A	1,310	0.329	431	4,020
B	1,370	0.329	451	
SUM			2,188	12,870
AVE.			438	4,290
S.D.			37	
C.V.			8.4	
<u>4,000 p.s.i. DESIGN</u>				
BEAM TEMP. - <u>+31</u> °F				
W - <u>6.4</u> %				
7 A	1,730	0.334	578	5,780
B	1,410	0.322	454	
8 A	1,900	0.324	616	5,640
B	1,815	0.316	574	
9 A	1,765	0.320	565	6,080
B	1,655	0.328	543	
SUM			3,330	17,500
AVE.			555	5,830
S.D.			55	
C.V.			9.9	

SUMMARY OF CYLINDER TESTS

192

BATCH- 10 AGE- 4 MON.
DATE- DEC. 26, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL. RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
<u>2,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u> </u> %	
0	0				0	1	2,924
3,000	425	55 1/2	6	9	1.90	2	2,932
6,000	850	132 1/2	"	22	2.23	3	2,467
9,000	1,275	232 1/2	"	38 1/2	3.91	4	3,169
12,000	1,700	356 1/2	"	59	5.99	5	2,787
15,000	2,120	525	"	87	8.83	6	2,924
18,000	2,550	554	5	111	11.27	SUM	17,203
						AVE.	2,870
						S.D.	260
						C.V.	9.0
<u>3,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u> </u> %	
0	0				0	7	4,786
3,000	425	39	6	6 1/2	0.65	8	4,555
6,000	850	101 1/2	"	17	1.73	9	4,485
9,000	1,275	177 1/2	"	29 1/2	2.99	10	3,974
12,000	1,700	261	"	43 1/2	4.41	11	4,003
15,000	2,120	365	"	61	6.19	12	
18,000	2,550	417 1/2	5	83	8.42	SUM	21,803
21,000	2,970	484	"	97	9.84	AVE.	4,360
24,000	3,440	616	"	123	12.48	S.D.	320
27,000	3,820	785	"	157	15.94	C.V.	7.4
<u>4,000 p.s.i. DESIGN</u>						Cylinder Temp. <u>+49°F</u> , W <u> </u> %	
0	0				0	13	5,489
5,000	708	65 1/2	5	13	1.32	14	6,367
10,000	1,420	159	"	32	3.25	15	5,337
15,000	2,120	261 1/2	"	52	5.28	16	6,012
20,000	2,830	376	"	73	7.41	17	5,373
25,000	3,540	506 1/2	"	101	10.25	18	
30,000	4,250	643 1/2	"	129	13.09	SUM	28,578
35,000	4,960	828	"	166	16.85	AVE.	5,710
						S.D.	450
						C.V.	7.9

SUMMARY OF BEAM TESTS

193

BATCH - 10 AGE - 4 MON.

DATE - DEC. 26, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 6.5 %				
1 A	1,175	0.332	390	3,280
B	920	0.321	295	
2 A	1,015	0.327	332	2,960
B	1,125	0.336	378	
3 A	955	0.324	309	2,760
B	1,110	0.320	355	
SUM			2,059	9,000
AVE.			343	3,000
S.D.			38	
C.V.			11.0	
3,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 6.3 %				
4 A	1,590	0.301	479	4,430
B	1,445	0.304	439	
5 A				
B				
6 A	1,530	0.319	488	4,540
B	1,460	0.314	458	
SUM			1,864	8,970
AVE.			466	4,480
S.D.				
C.V.				
4,000 p.s.i. DESIGN				
BEAM TEMP. - $+49^{\circ}\text{F}$				
W - 6.1 %				
7 A	1,495	0.335	501	5,370
B	1,630	0.333	543	
8 A	1,630	0.330	538	5,000
B	1,470	0.325	478	
9 A	1,715	0.328	563	5,560
B	1,540	0.312	480	
SUM			3,103	15,930
AVE.			517	5,310
S.D.			36	
C.V.			6.9	

SUMMARY OF CYLINDER TESTS 194

BATCH- 4 AGE- 4 MON.
DATE- OCT. 31, 60

STRESS - STRAIN						ULTIMATE	
LOAD pounds	STRESS p.s.i.	SUM DIAL RDG'S.	NO. of RDG.	AVE. DIAL RDG.	UNIT STRAIN $\times 10^{-4}$	CYL. NO.	ULT. STRESS p.s.i.
2,000 p.s.i. DESIGN						Cylinder Temp. $\pm 74^{\circ}\text{F}$, W 7.7 %	
0	0				0	1	2,895
3,000	425	77	6	13	1.32	2	2,532
6,000	850	143 1/2	-	24	2.44	3	3,027
9,000	1,275	243 1/2	-	40 1/2	4.11	4	2,914
12,000	1,700	371 1/2	-	62	6.29	5	2,787
15,000	2,120	547	-	91	9.24	6	2,773
18,000	2,550	526	4	132	13.40	SUM	16,928
						AVE.	2,820
						S.D.	200
						C.V.	7.0
3,000 p.s.i. DESIGN						Cylinder Temp. $\pm 74^{\circ}\text{F}$, W 7.1 %	
0	0				0	7	4,585
3,000	425	42 1/2	6	7	0.70	8	4,273
6,000	850	106	-	18	1.83	9	4,244
9,000	1,275	184	-	31	3.15	10	4,343
12,000	1,700	269 1/2	-	45	4.57	11	4,598
15,000	2,120	365 1/2	-	61	6.19	12	4,201
18,000	2,550	470 1/2	-	78	7.92	SUM	26,244
21,000	2,970	588	-	98	9.95	AVE.	4,370
24,000	3,400	749	-	125	12.69	S.D.	175
27,000	3,820	760	5	152	15.43	C.V.	4.0
4,000 p.s.i. DESIGN						Cylinder Temp. $\pm 74^{\circ}\text{F}$, W 7.4 %	
0	0				0	13	5,877
4,000	567	49 1/2	5	10	1.01	14	5,768
8,000	1,130	145 1/2	6	24	2.44	15	5,234
12,000	1,700	252	-	42	4.26	16	5,941
16,000	2,270	292	5	58	5.89	17	5,309
20,000	2,830	385	-	77	7.82	18	5,451
24,000	3,400	503	-	101	10.25	SUM	33,580
28,000	3,970	615	-	123	12.48	AVE.	5,600
32,000	4,530	749	-	150	15.23	S.D.	310
36,000	5,100	904	-	181	18.37	C.V.	5.5

SUMMARY OF BEAM TESTS

 BATCH - 4 AGE - 4 MON.

 DATE - OCT. 31, 60

FLEXURAL STRENGTH				MODIFIED CUBE STRENGTH psi
BEAM NO.	LOAD pounds	MULT. FACTOR	MODULUS of RUPTURE psi	
2,000 p.s.i. DESIGN BEAM TEMP. - $+74^{\circ}\text{F}$ W - 7.6%				
1 A	945	0.327	309	2,680
B	810	0.321	260	
2 A	945	0.324	306	2,830
B	990	0.321	318	
3 A	985	0.326	321	3,070
B	660	0.325	215	
		SUM	1,729	8,580
		AVE.	288	2,860
		S.D.	43	
		C.V.	15.0	
3,000 p.s.i. DESIGN BEAM TEMP. - $+74^{\circ}\text{F}$ W - 7.1%				
4 A	1,310	0.329	431	4,480
B	1,590	0.324	515	
5 A	1,235	0.328	405	4,770
B	1,190	0.329	391	
6 A	1,360	0.326	447	4,550
B	1,520	0.323	491	
		SUM	2,680	13,800
		AVE.	447	4,600
		S.D.	48	
		C.V.	10.8	
4,000 p.s.i. DESIGN BEAM TEMP. - $+74^{\circ}\text{F}$ W - 7.3%				
7 A	1,730	0.329	569	6,100
B	1,675	0.327	548	
8 A	1,610	0.330	531	6,180
B	1,815	0.330	599	
9 A	1,740	0.322	560	4,270
B	1,480	0.335	496	
		SUM	3,303	16,550
		AVE.	550	5,520
		S.D.	35	
		C.V.	6.4	

SUMMARY OF STANDARD

CYLINDER TESTS

AGE - 4 MON.

BATCH	CYL. NO.	ULTIMATE STRENGTH p.s.i.		
		2,000 p.s.i. DESIGN	3,000 p.s.i. DESIGN	4,000 p.s.i. DESIGN
8	1 S	2,310	3,730	4,260
	2 S	2,280	3,430	5,870
	3 S	2,940	4,300	5,500
	SUM	7,530	11,460	15,630
	AVE.	2,510	3,820	5,210
9	1 S	2,640	5,080	5,690
	2 S	2,890	4,530	
	3 S	2,670	4,550	5,850
	SUM	8,200	14,160	11,540
	AVE.	2,730	4,720	5,770
10	1 S	2,910	4,320	
	2 S	2,900	4,540	5,510
	3 S	2,730	4,000	4,700
	SUM	8,540	12,860	10,210
	AVE.	2,850	4,290	5,110

A P P E N D I X C

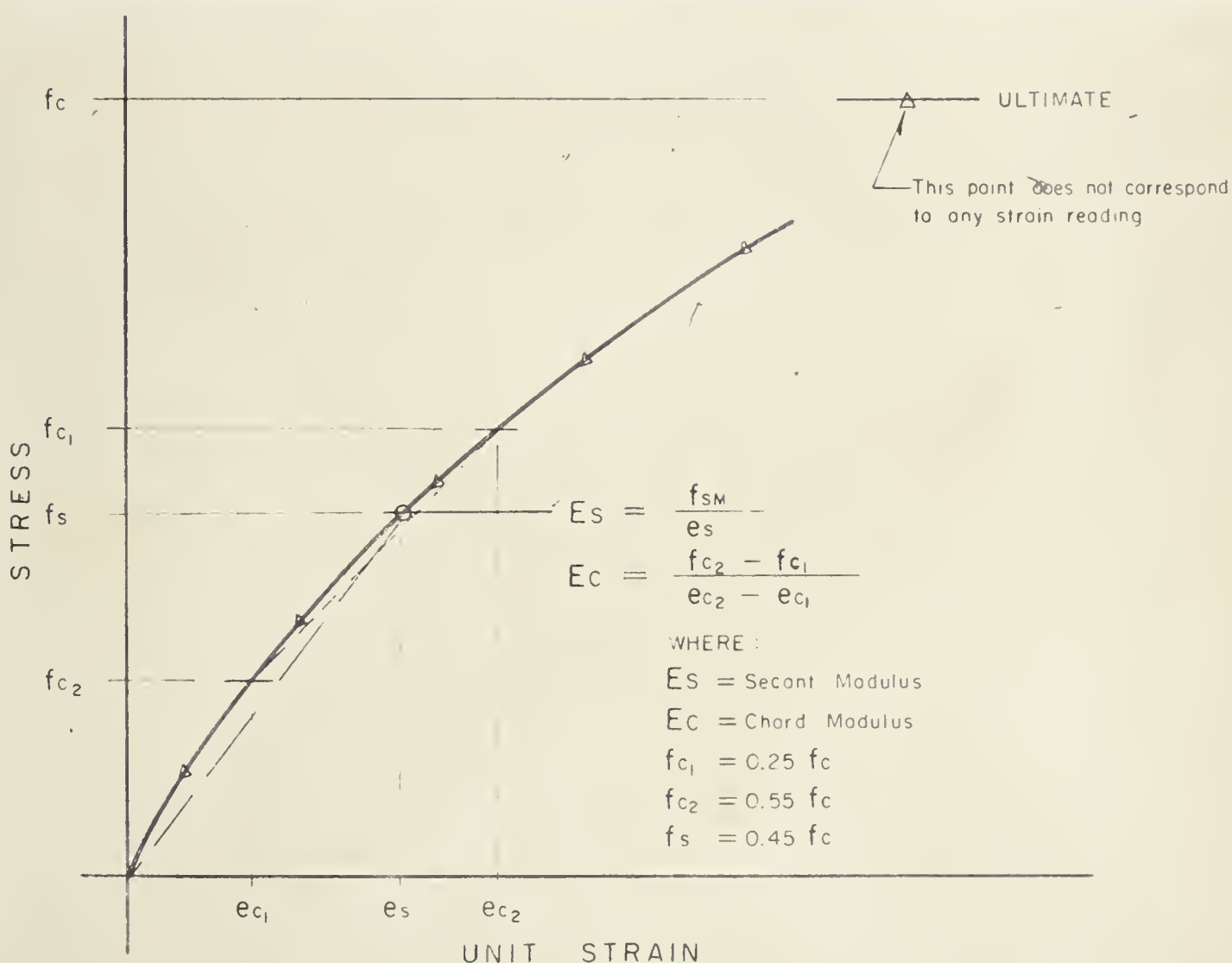
EXPLANATION OF STRESS-STRAIN CURVES

Values of stress and strain were computed as indicated at the beginning of Appendix B and are presented in the data sheets of Appendix B. It must be noted that:

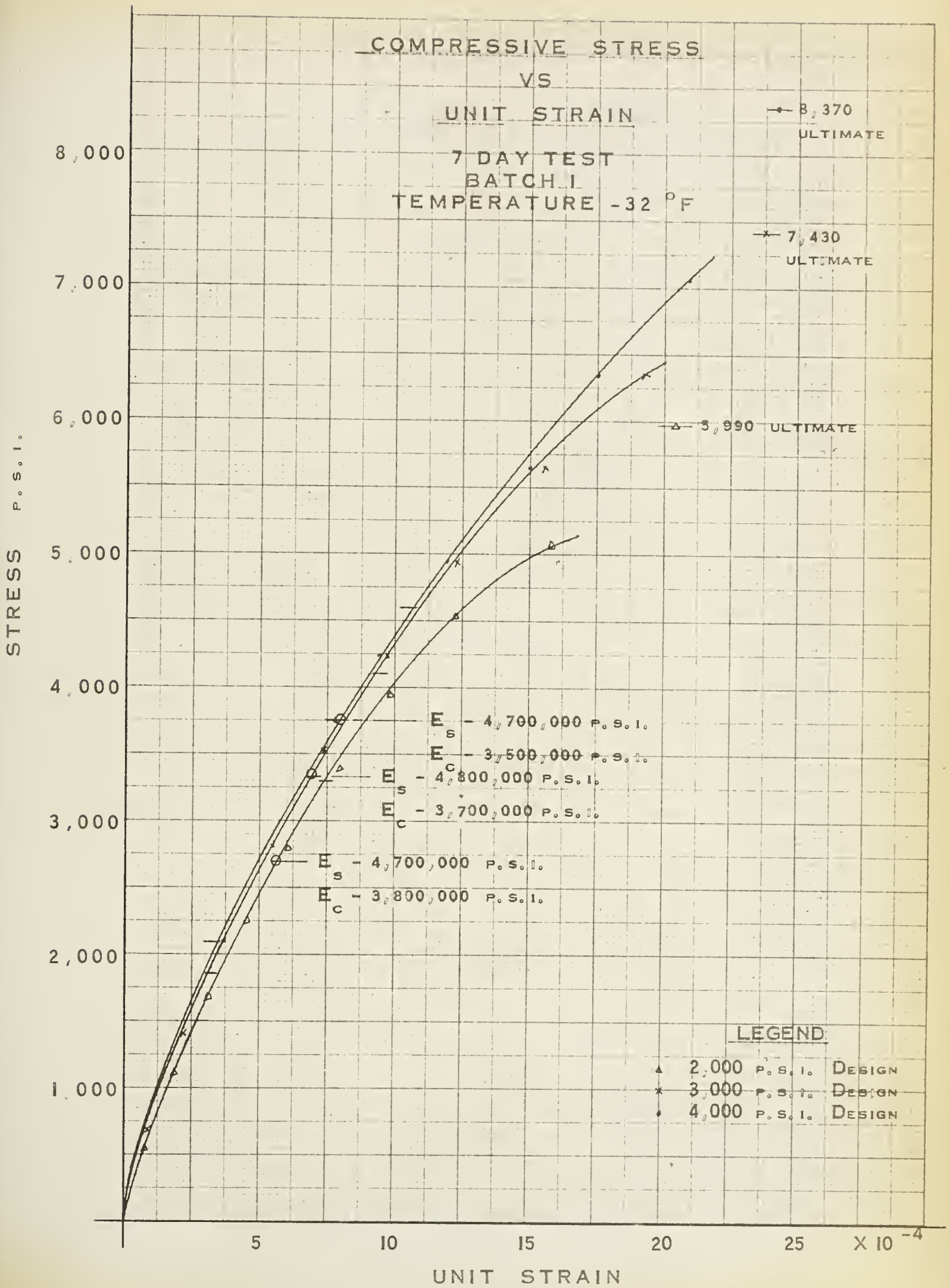
- i) Values of stress were obtained by dividing the load by an average area which was determined by measurements of a number of specimens. Cylinder diameters measured at the time of test varied between the limits of 2.985 and 3.010 inches. Consequently, considering the scale of the stress-strain curves, any error in stress values as a result of the forementioned method of computation would have a negligible effect on the values of the modulus of elasticity.
- ii) Values of unit strain are determined by averaging the six readings of a test group at a particular load. To check this method of presentation, individual stress-strain plots were made for all six cylinders of arbitrarily selected test groups. The averages of the values of the chord and secant moduli of elasticity from these plots compared

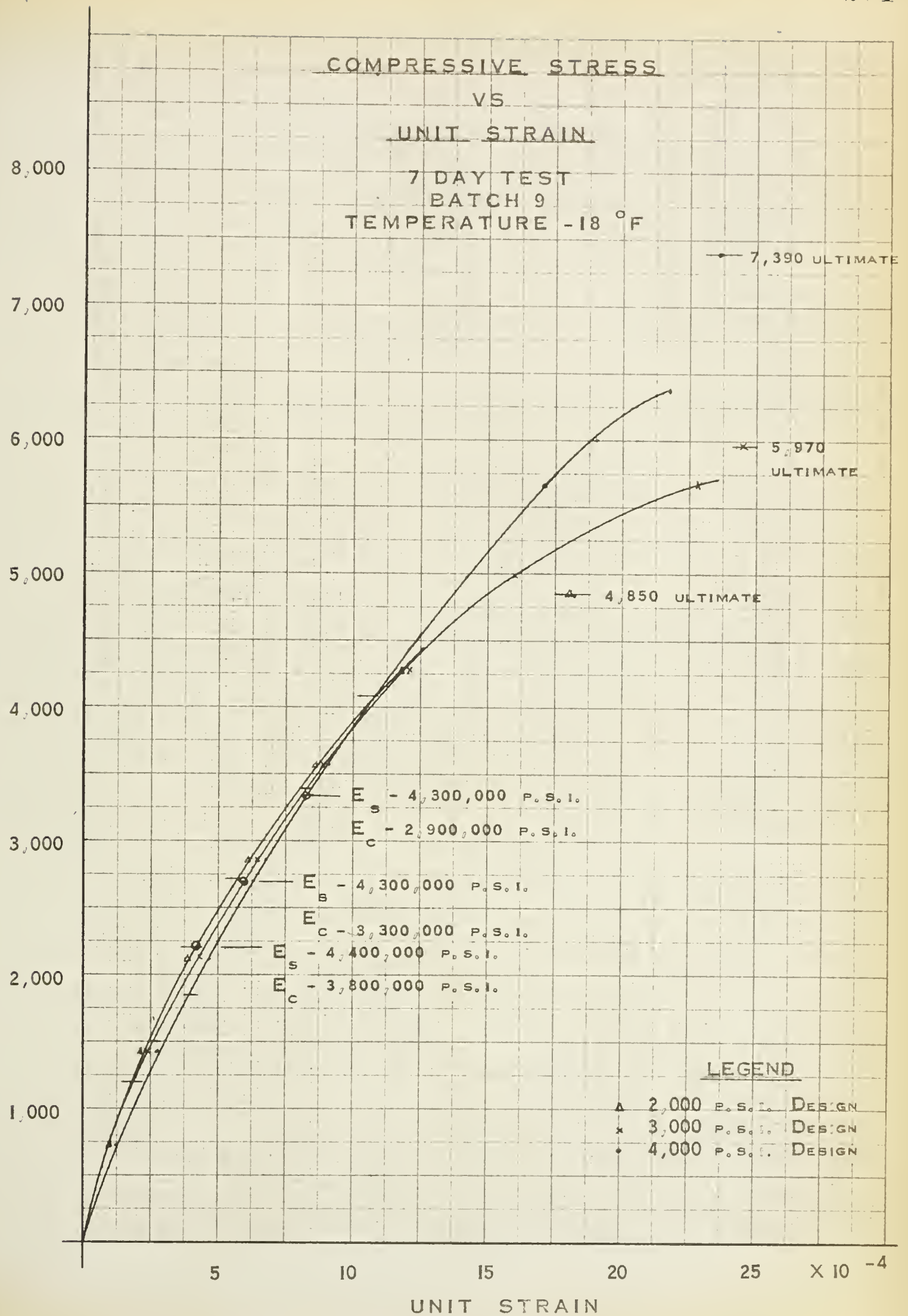
favorably with the moduli of elasticity obtained by averaging the strains and plotting only one stress-strain curve for each test group.

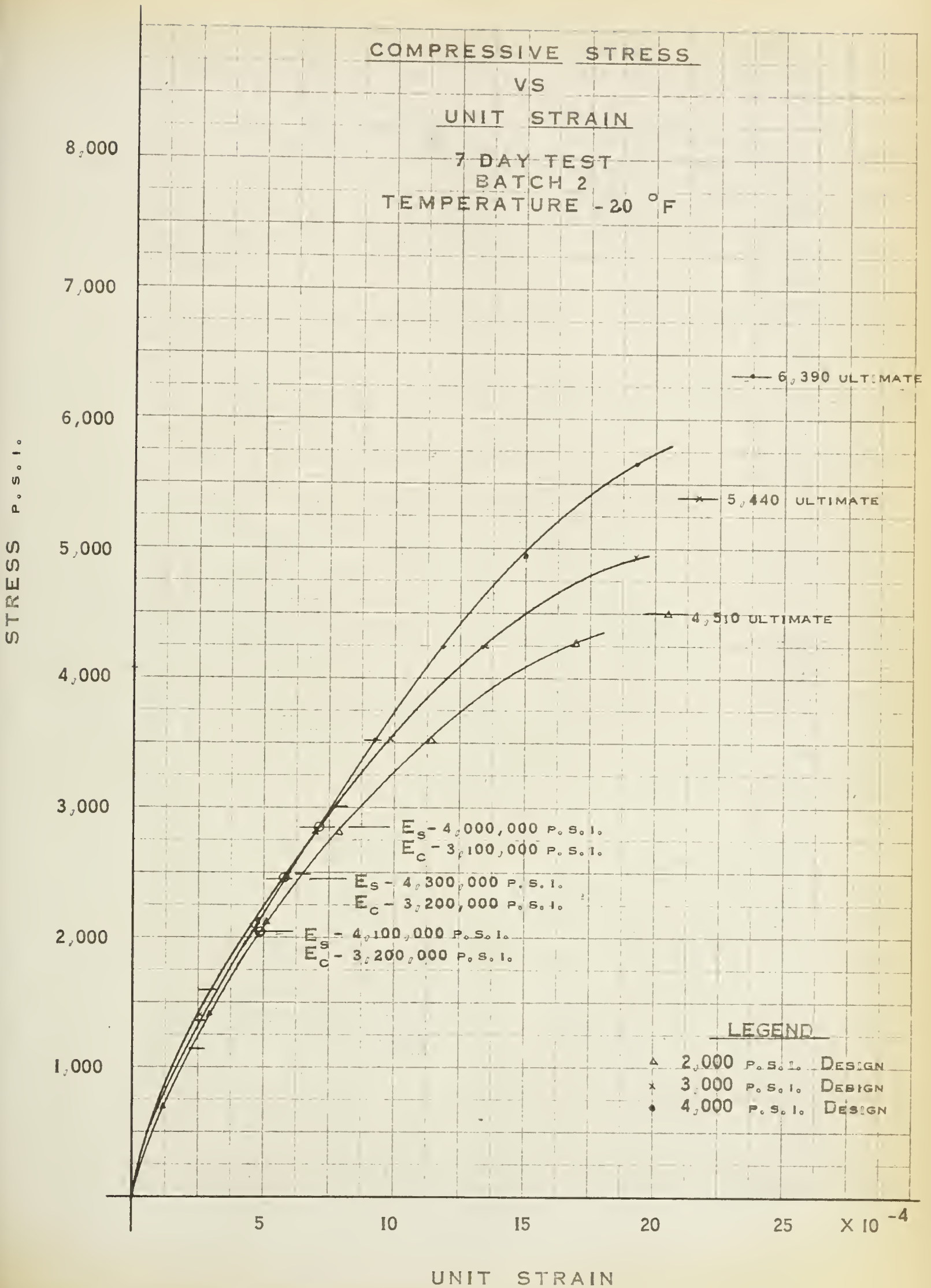
The definitions of the chord and secant moduli of elasticity as used for this report are given in Sect. 6.7. A graphical representation using the symbols of the following stress-strain curves is shown below.

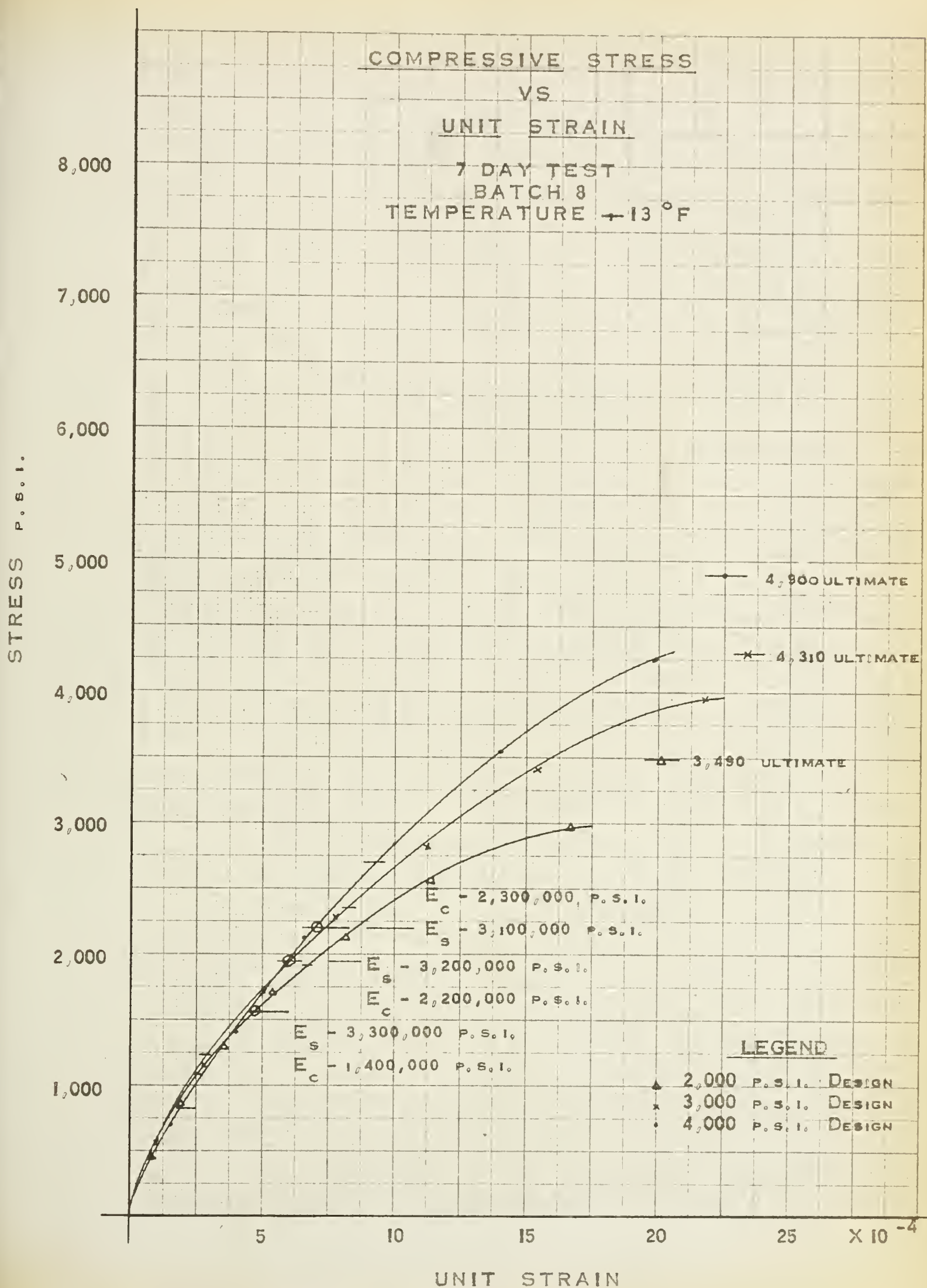


DEFINITION OF MODULI OF ELASTICITY









COMPRESSIVE STRESS
VS
UNIT STRAIN

7 DAY TEST
BATCH 3
TEMPERATURE $\pm 28^{\circ}\text{F}$

STRESS P.S.I.

4,000

3,500

3,000

2,500

2,000

1,500

1,000

500

 $E_C - 2,200,000 \text{ P.S.I.}$
 $E_S - 2,600,000 \text{ P.S.I.}$
 $E_S - 2,300,000 \text{ P.S.I.}$
 $E_C - 1,600,000 \text{ P.S.I.}$
 $E_S - 1,870,000 \text{ P.S.I.}$
 $E_C - 1,300,000 \text{ P.S.I.}$

LEGEND

- Δ 2,000 P.S.I. DESIGN
- $\times$ 3,000 P.S.I. DESIGN
- $\bullet$ 4,000 P.S.I. DESIGN

3,470
ULTIMATE

2,730
ULTIMATE

2,040
ULTIMATE

4

8

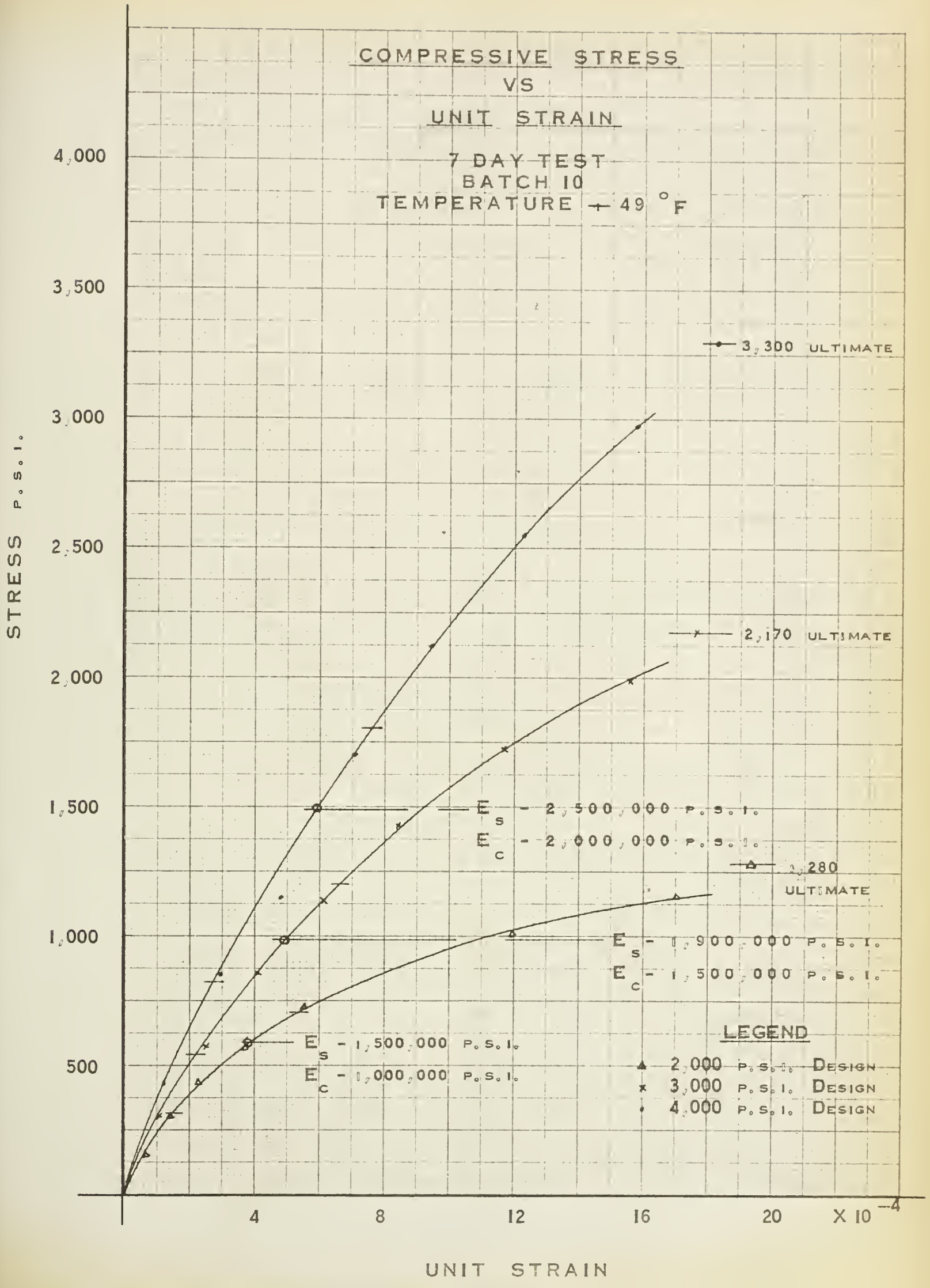
12

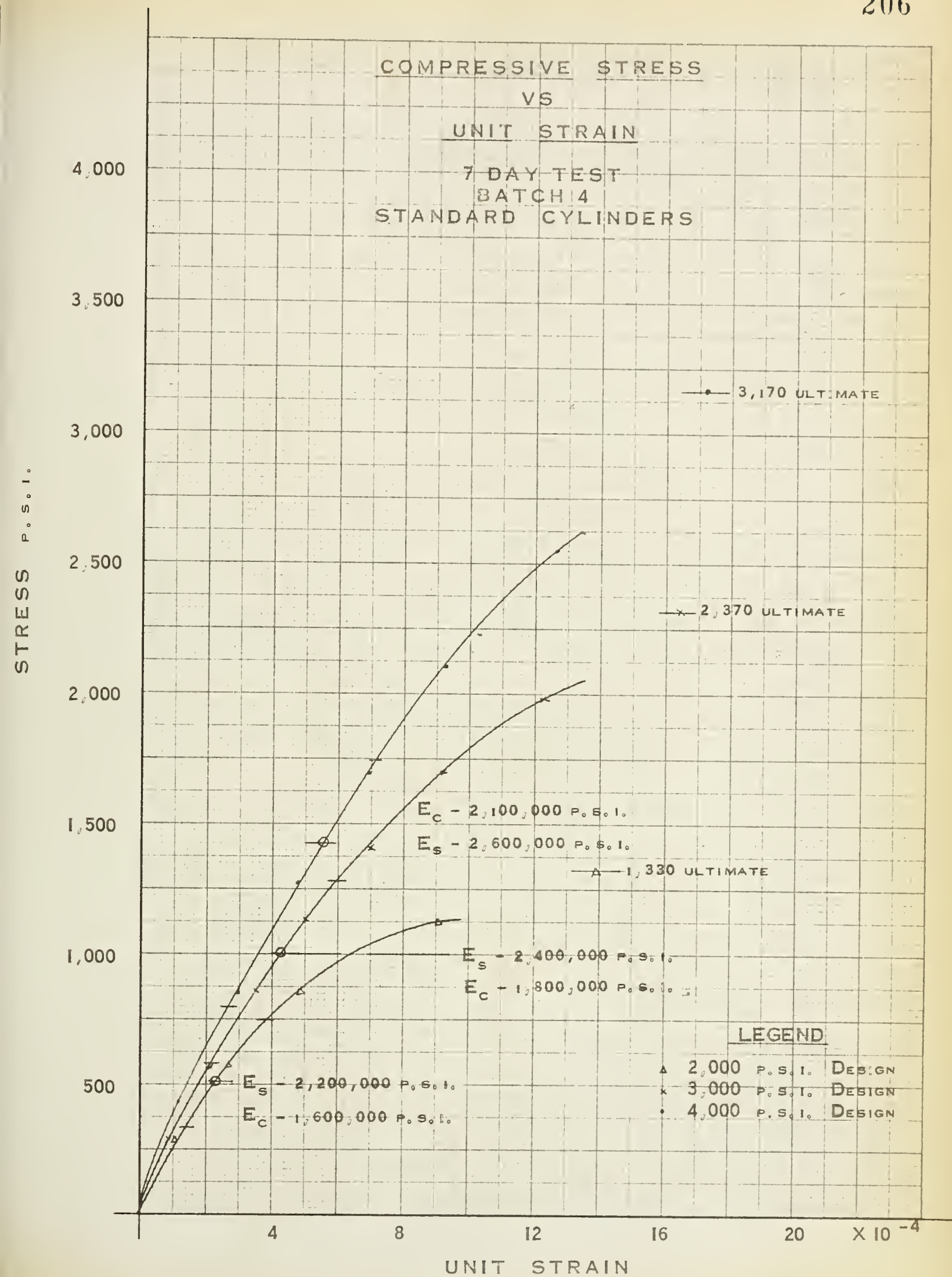
16

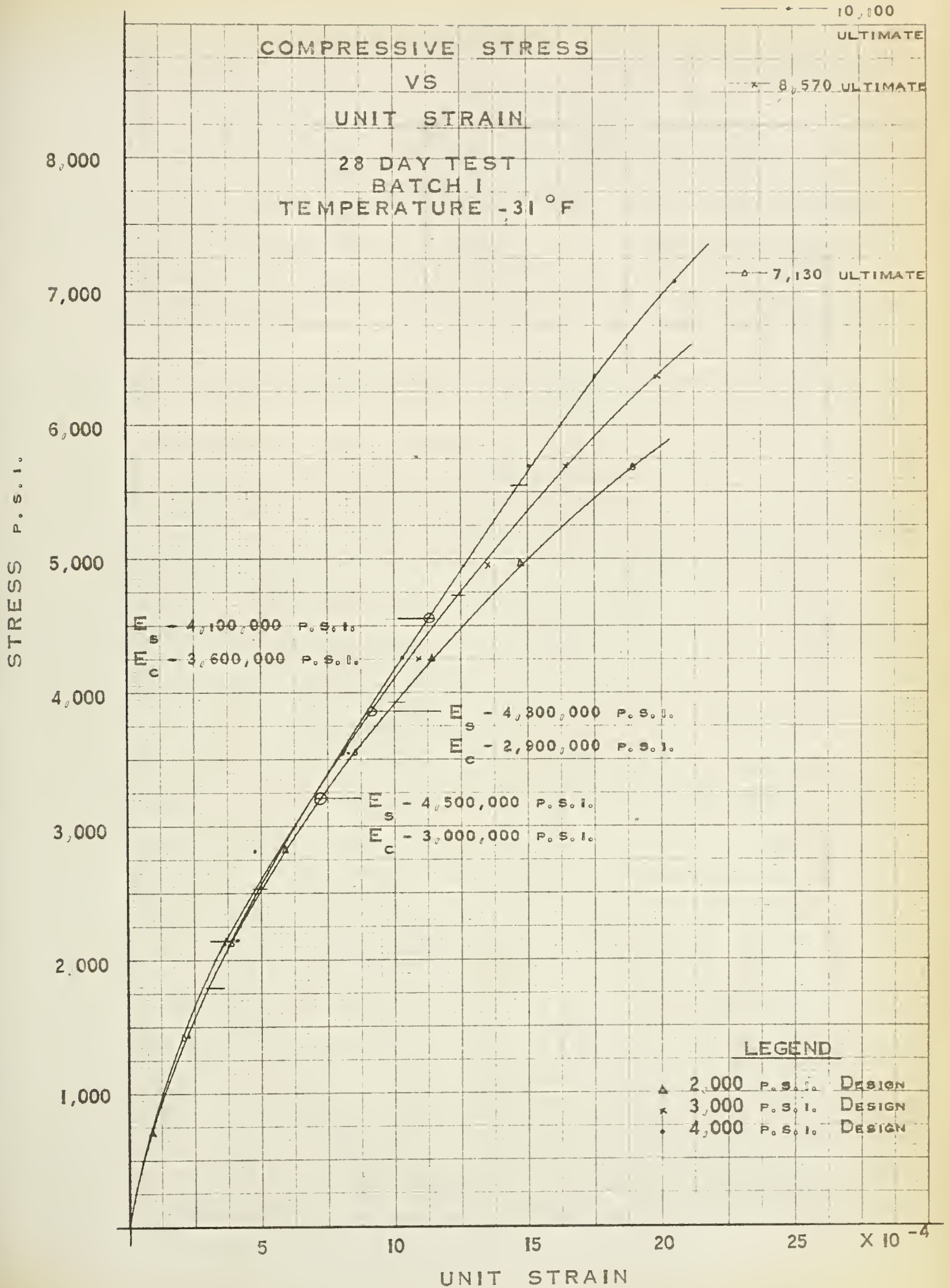
20

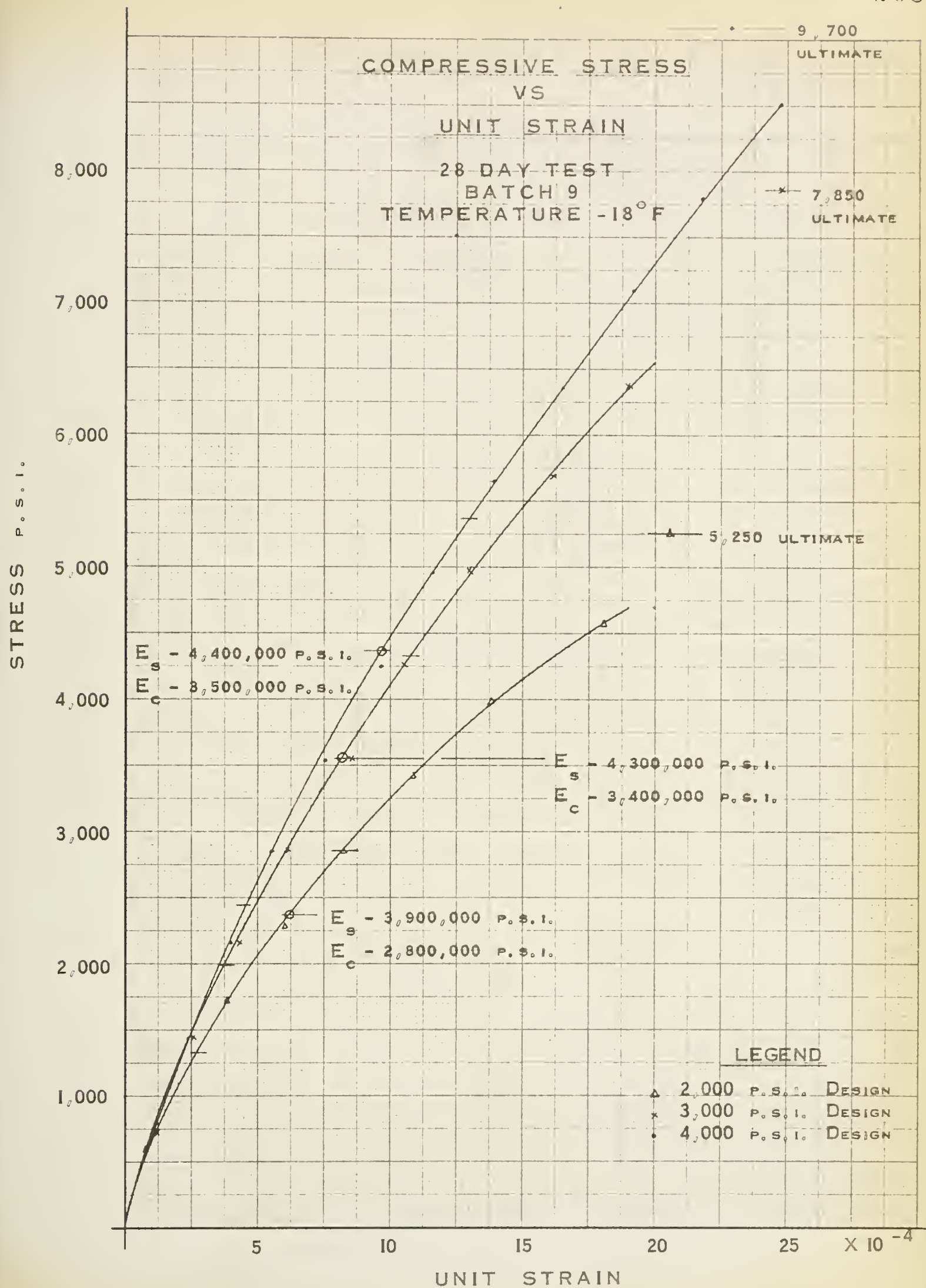
 $\times 10^{-4}$

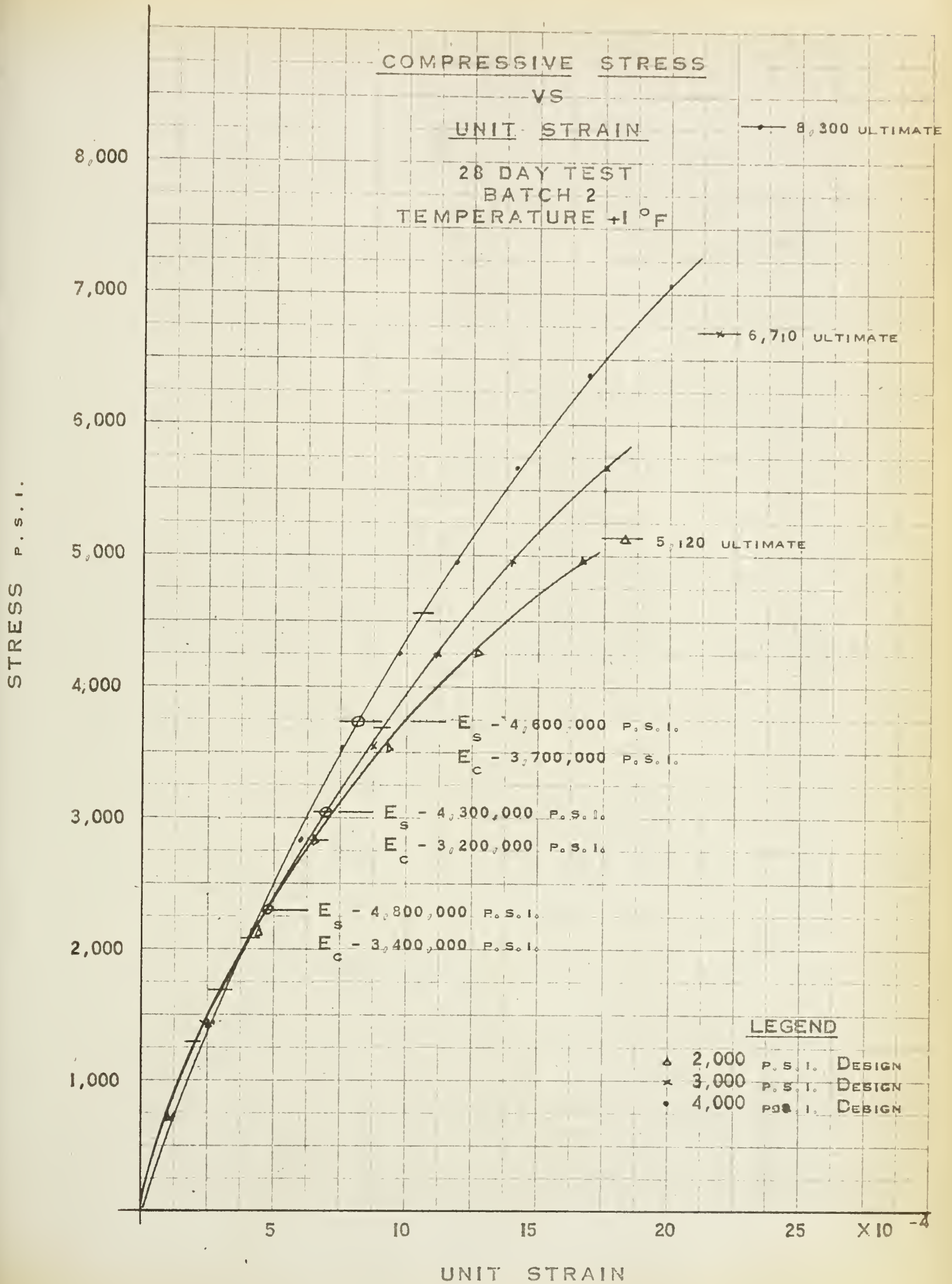
UNIT STRAIN

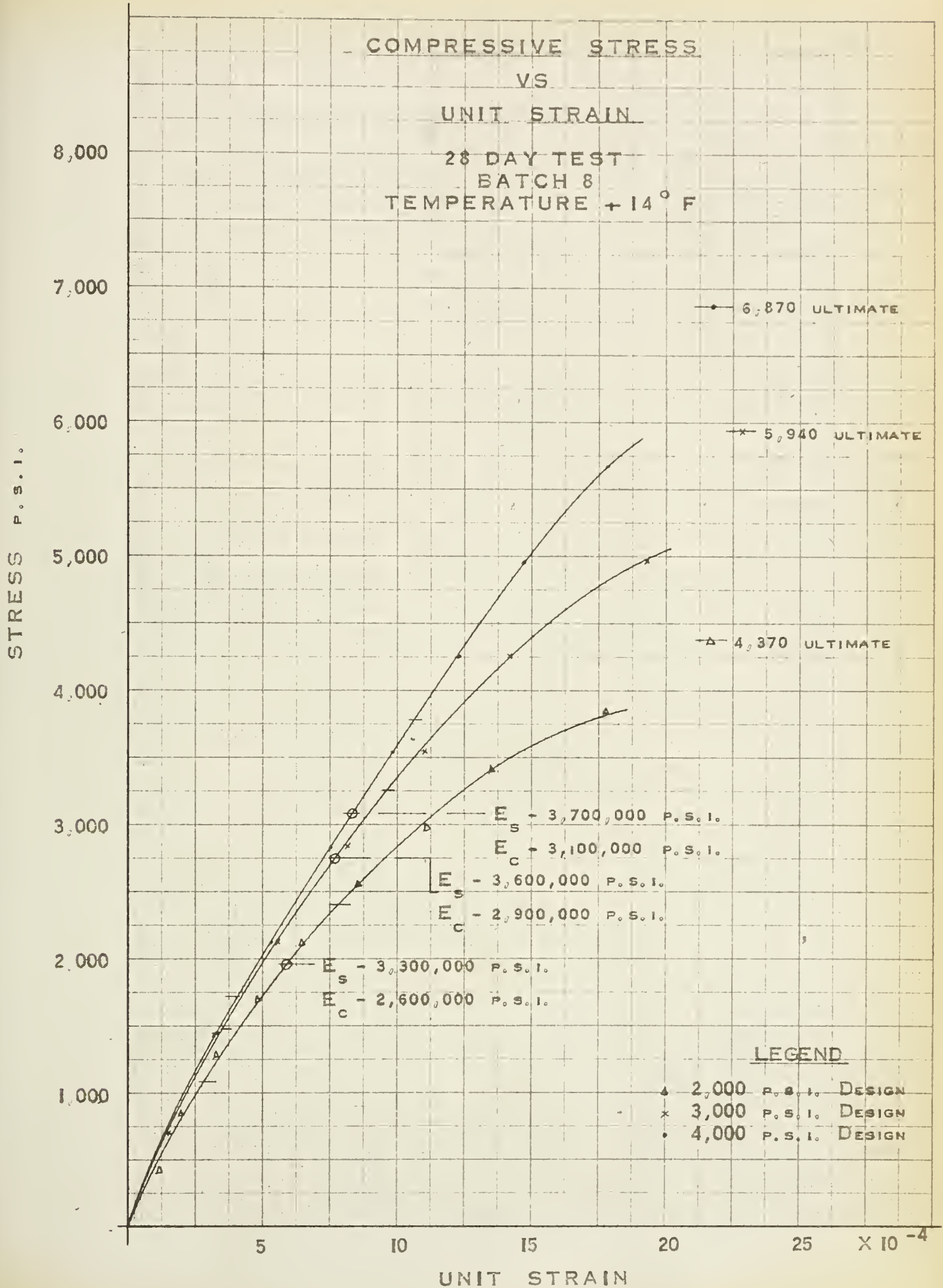


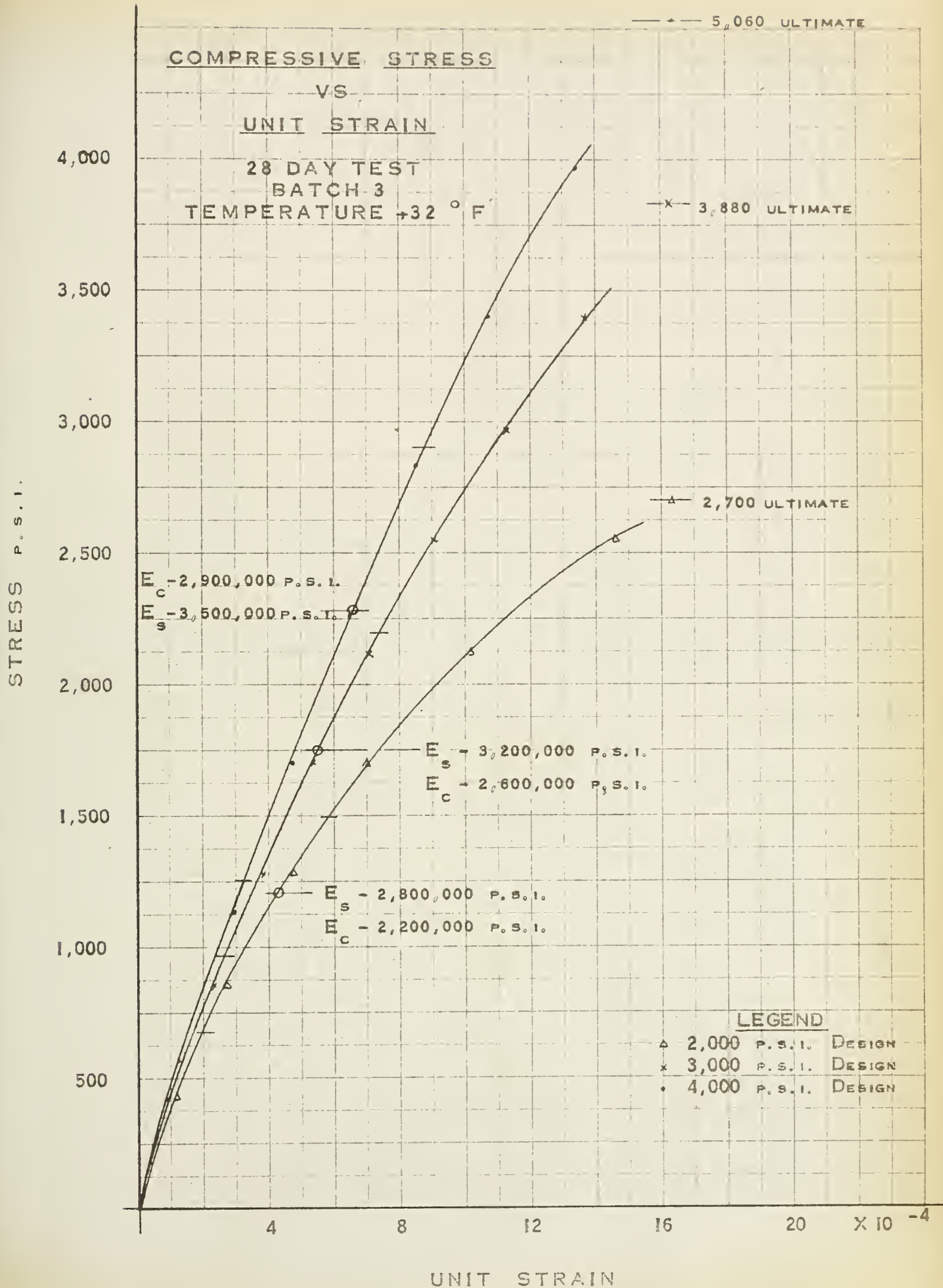












STRESS P.S.I.

COMPRESSIVE STRESS
VS
UNIT STRAIN

28 DAY TEST
BATCH 10
TEMPERATURE $+49^{\circ}\text{F}$

—♦— 4,870 ULTIMATE

4,000

3,500

3,000

2,500

2,000

1,500

1,000

500

* 3,510 ULTIMATE

△ 2,650 ULTIMATE

$E_s - 3,200,000$ P.S.I.

$E_c - 2,700,000$ P.S.I.

$E_s - 2,800,000$ P.S.I.

$E_c - 2,200,000$ P.S.I.

$E_s - 2,800,000$ P.S.I.

$E_c - 2,100,000$ P.S.I.

LEGEND

- △ 2,000 P.S.I. DESIGN
- * 3,000 P.S.I. DESIGN
- 4,000 P.S.I. DESIGN

4

8

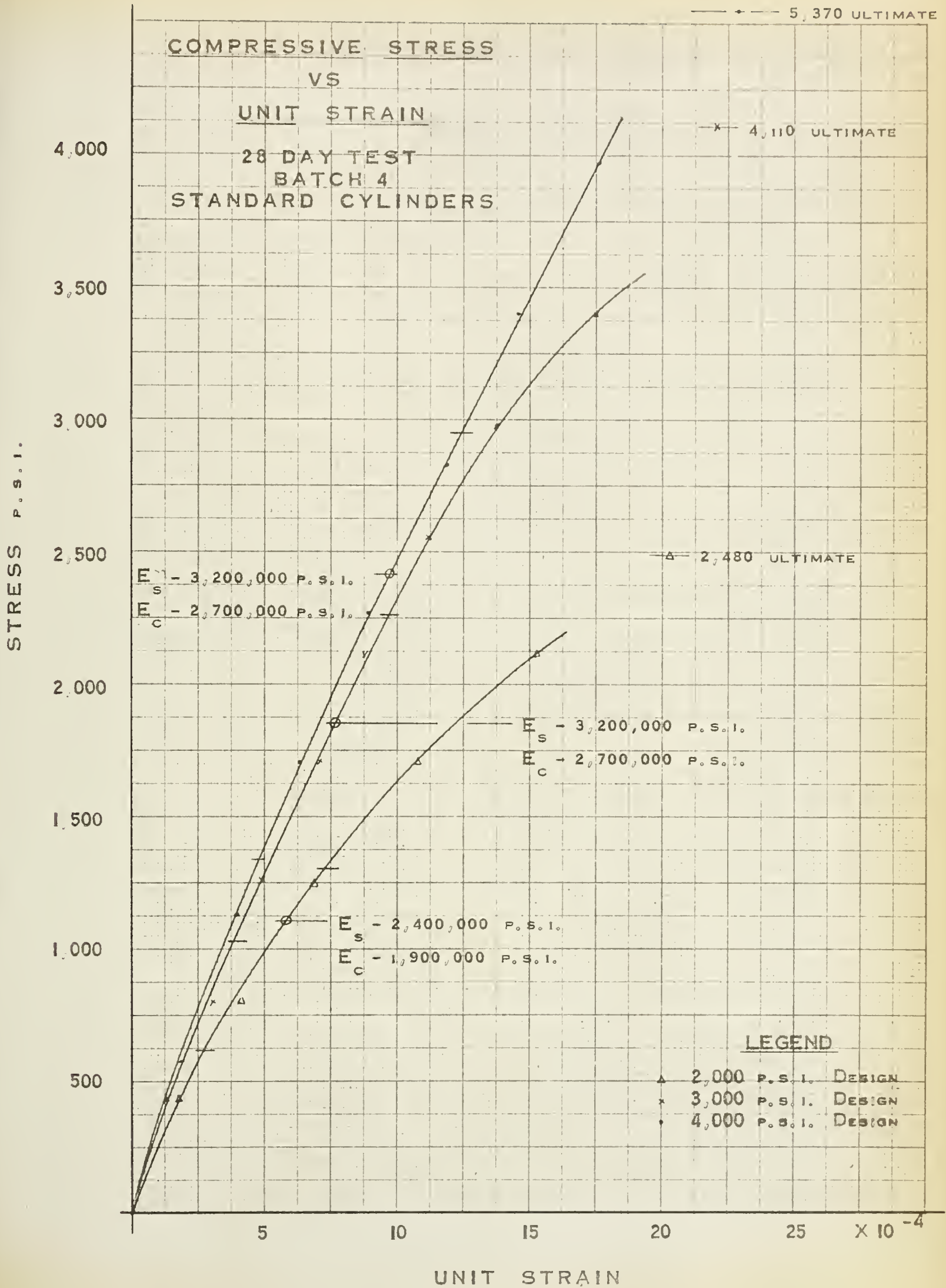
12

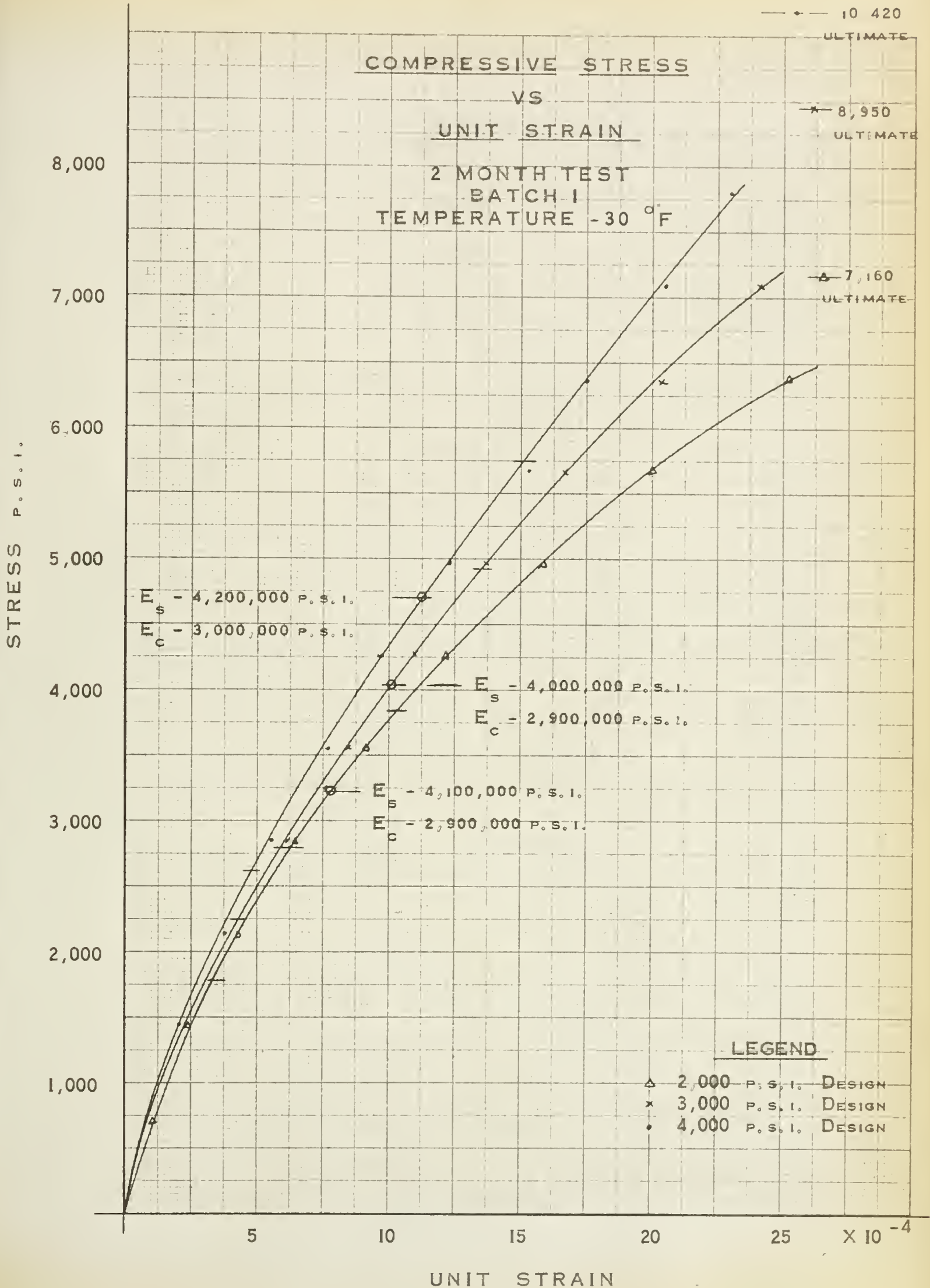
16

20

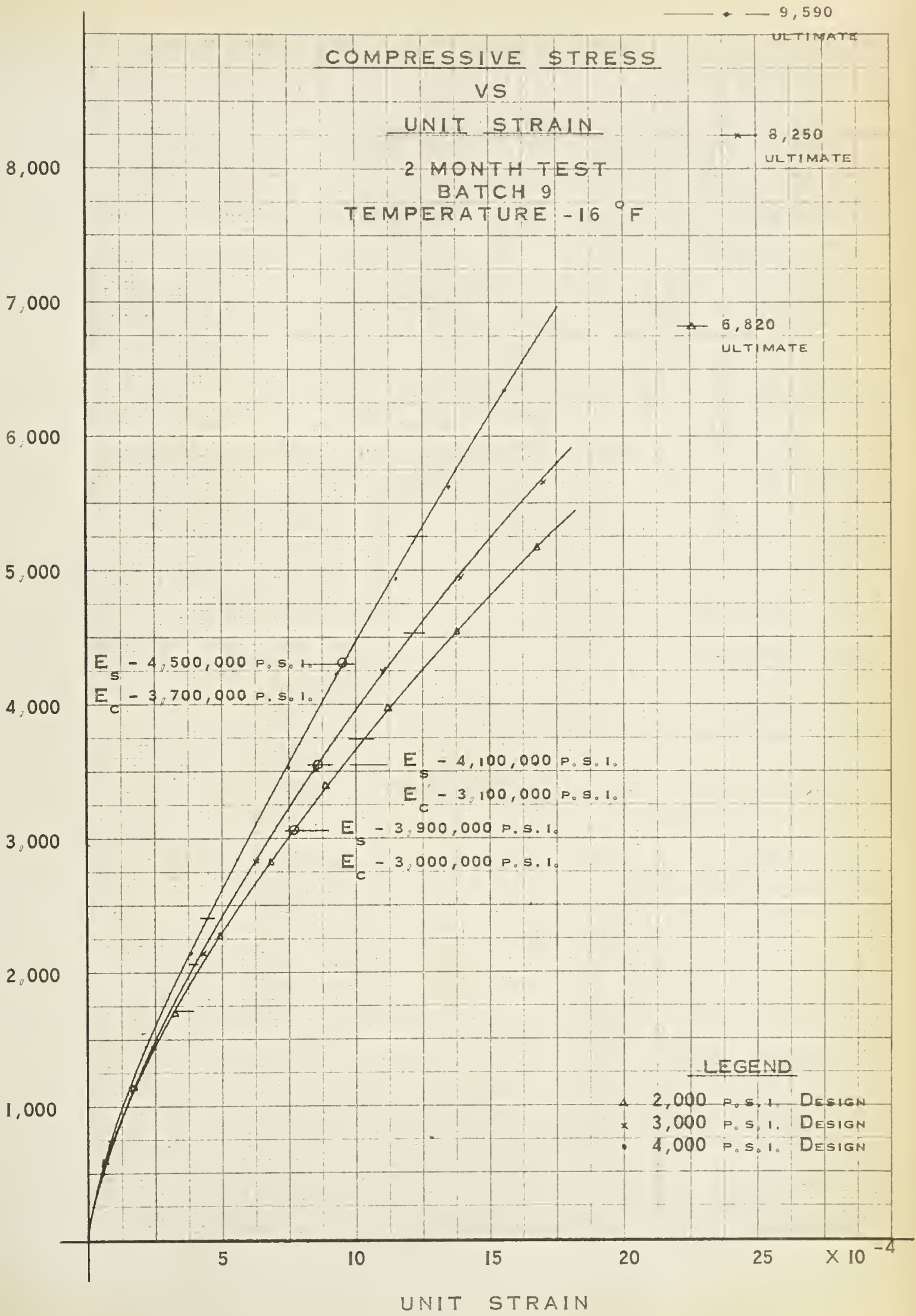
$\times 10^{-4}$

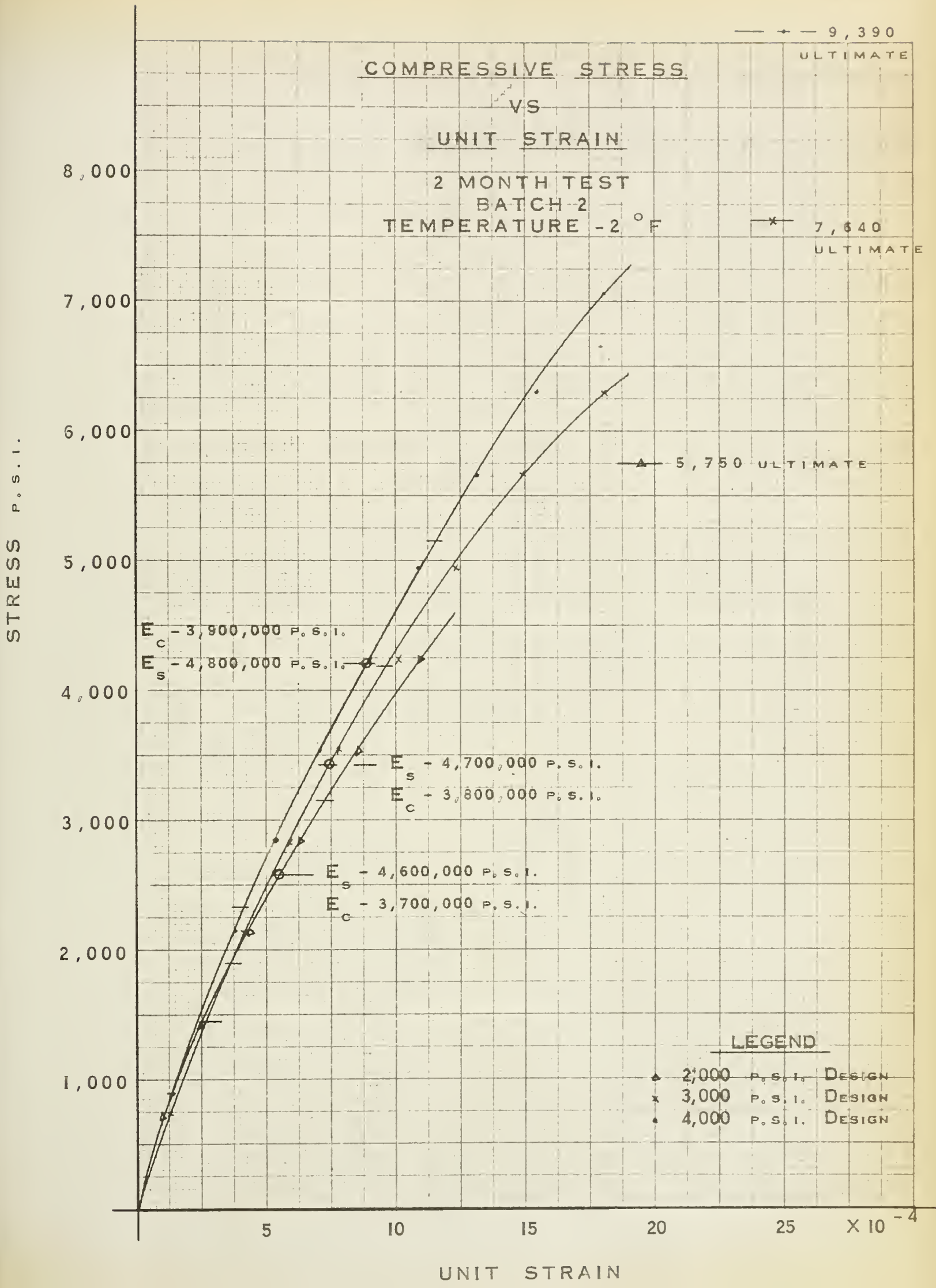
UNIT STRAIN

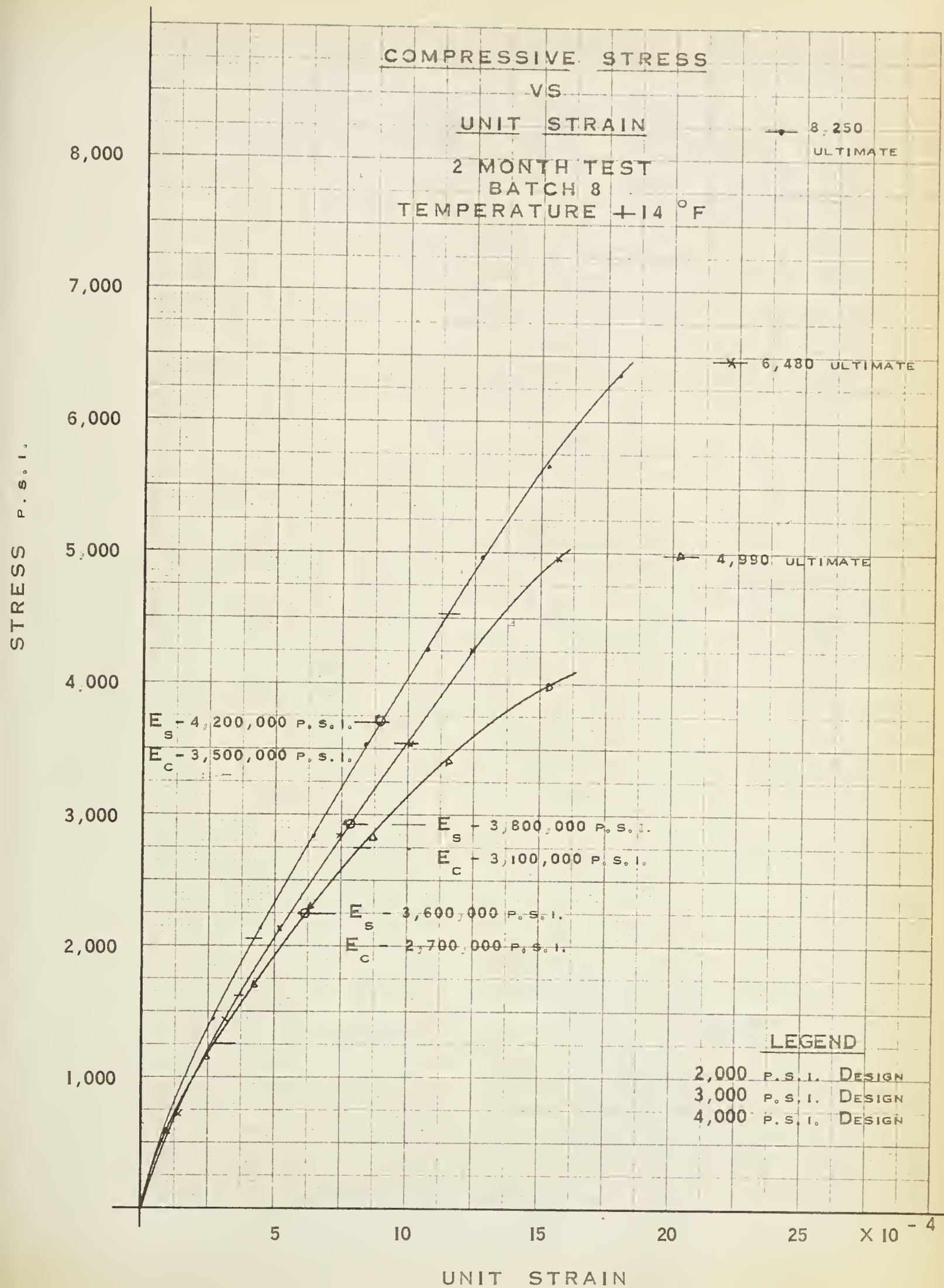


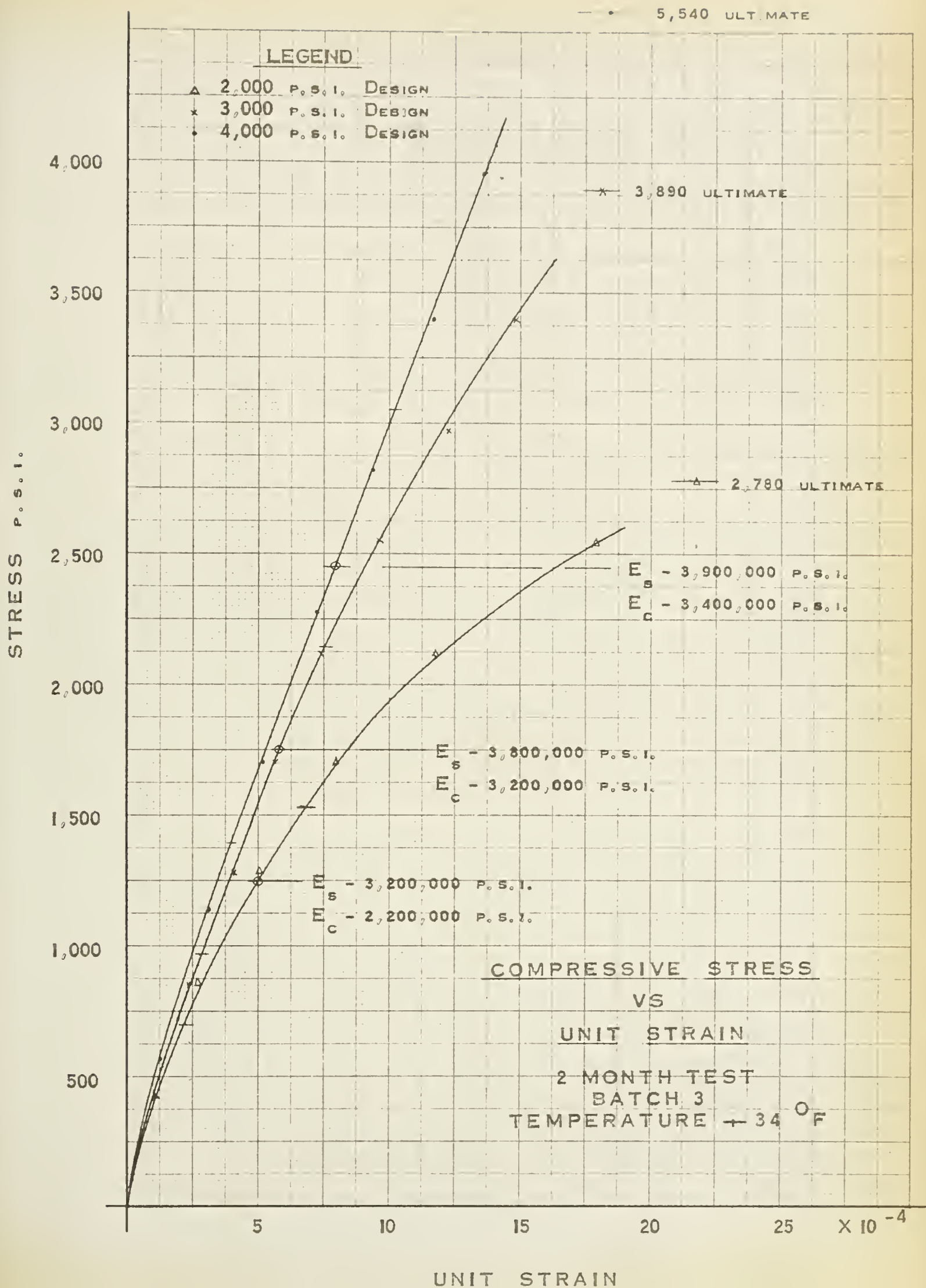


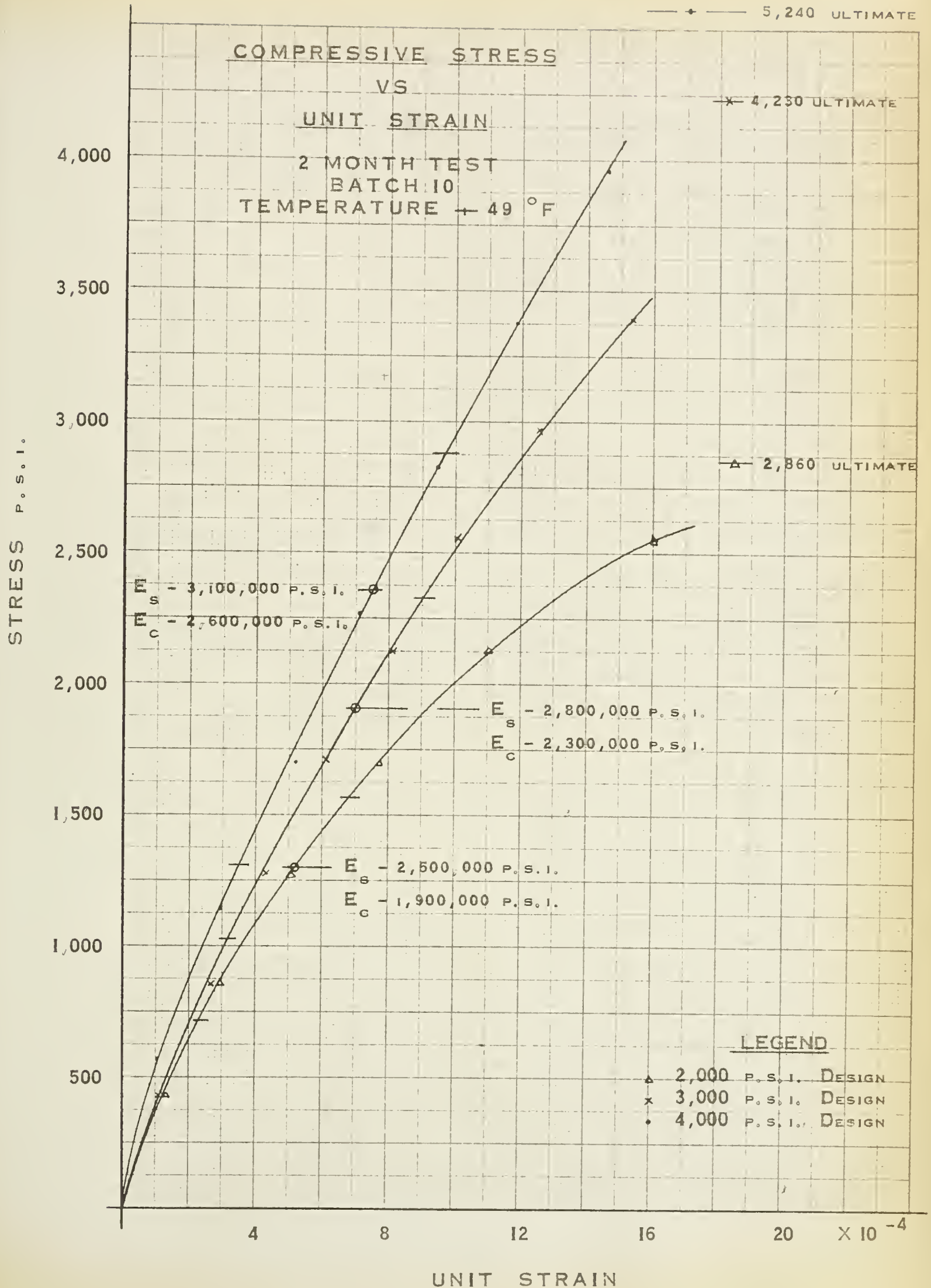
STRESS P. S. I.

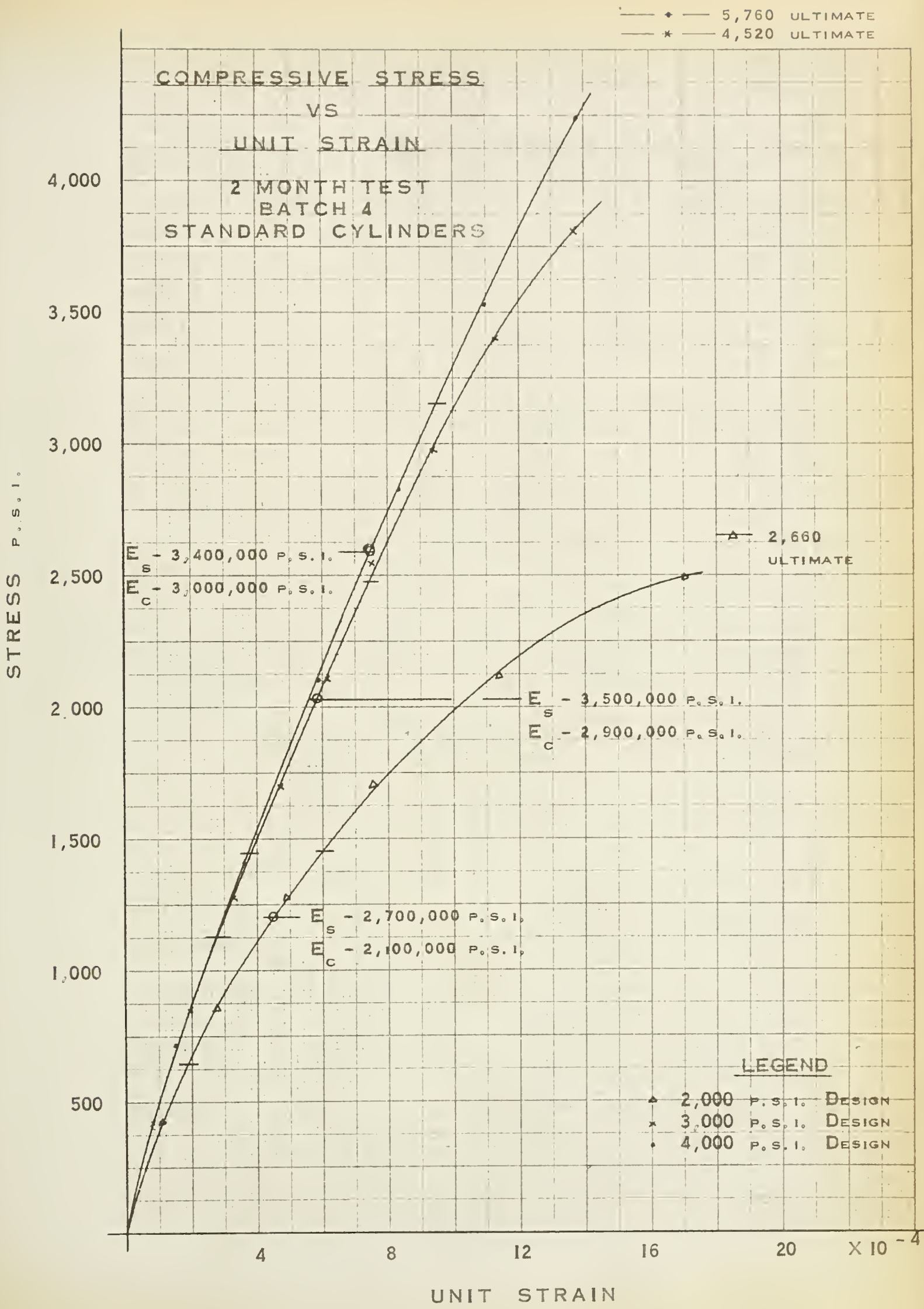


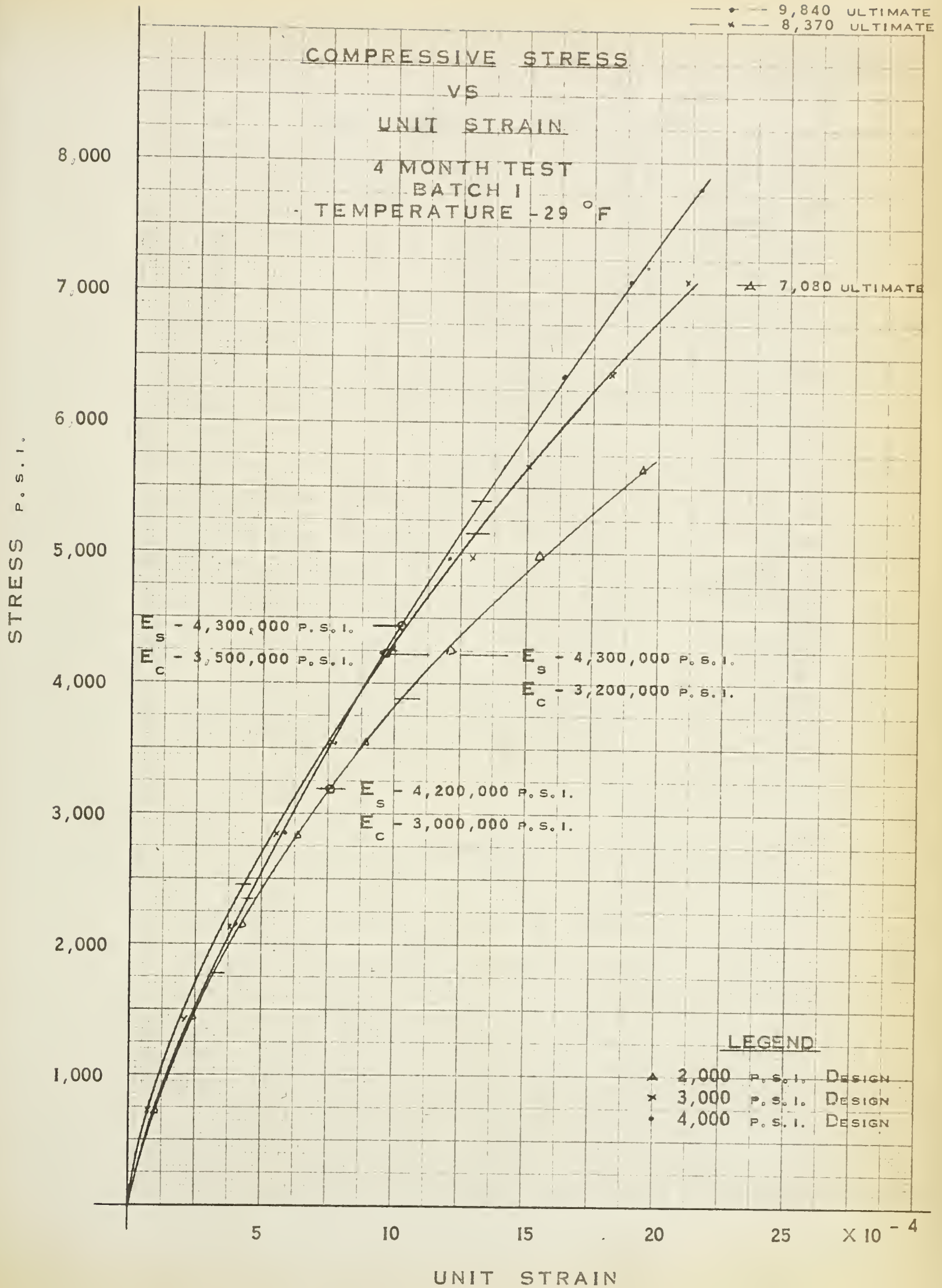


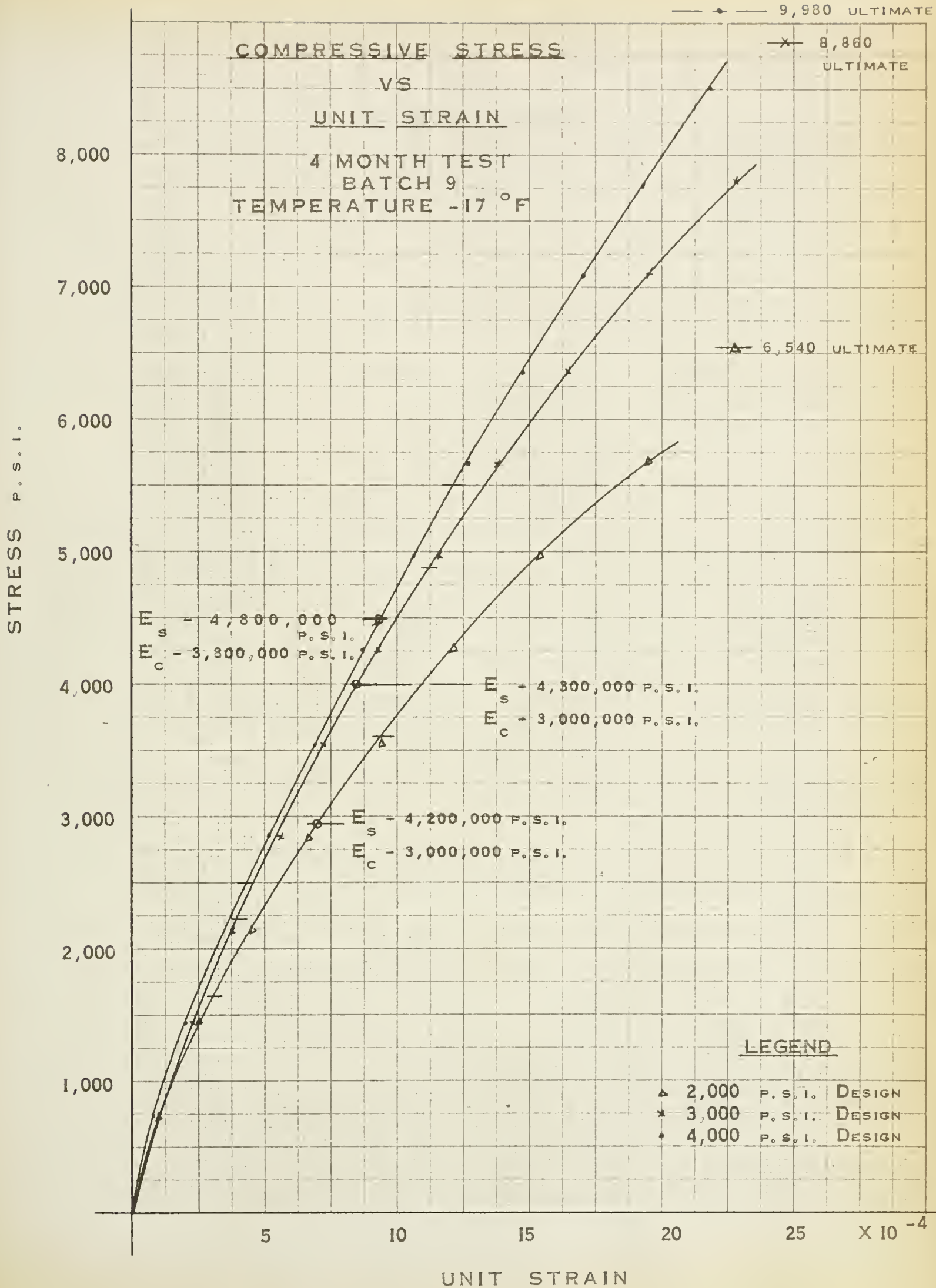


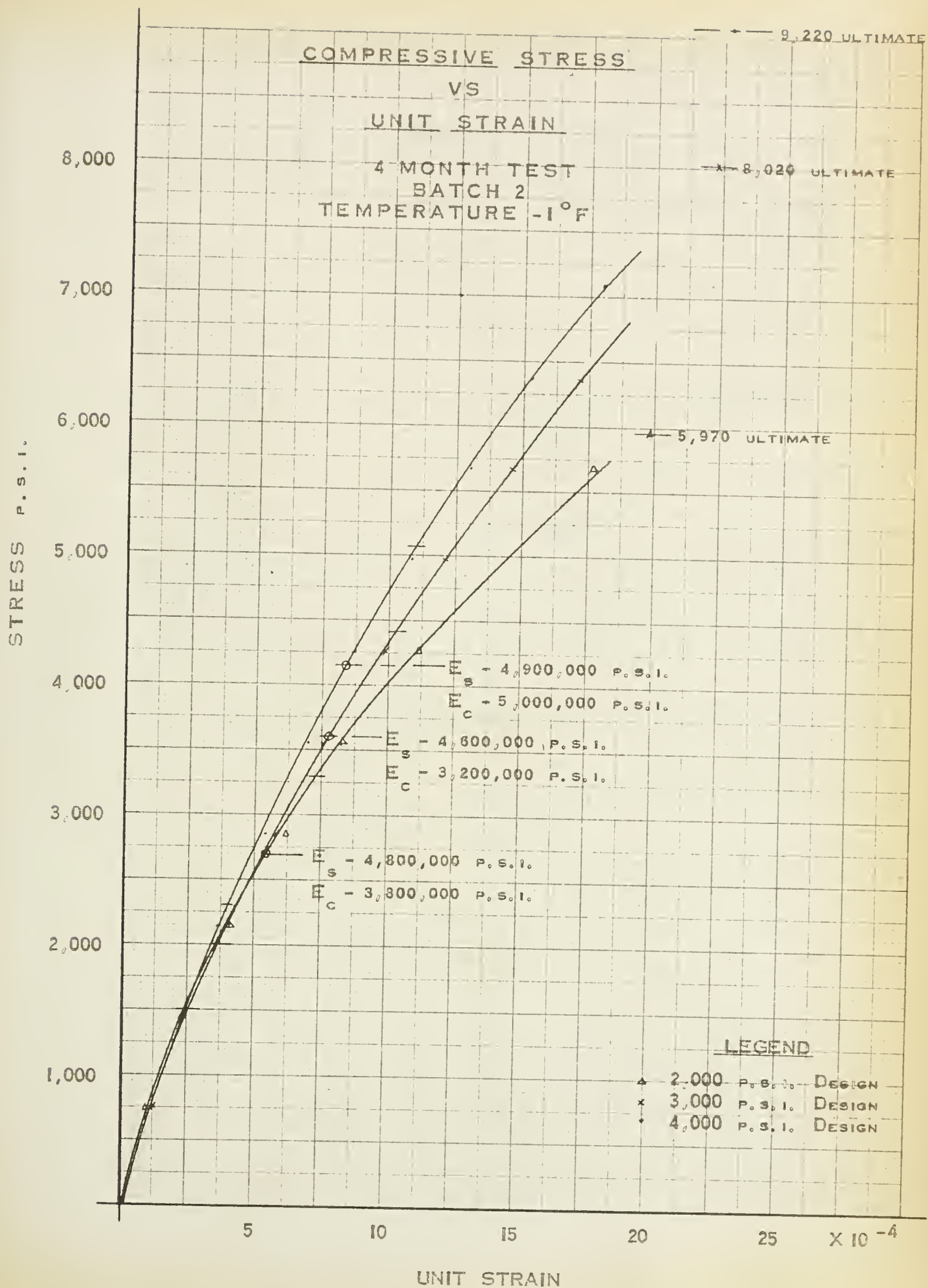


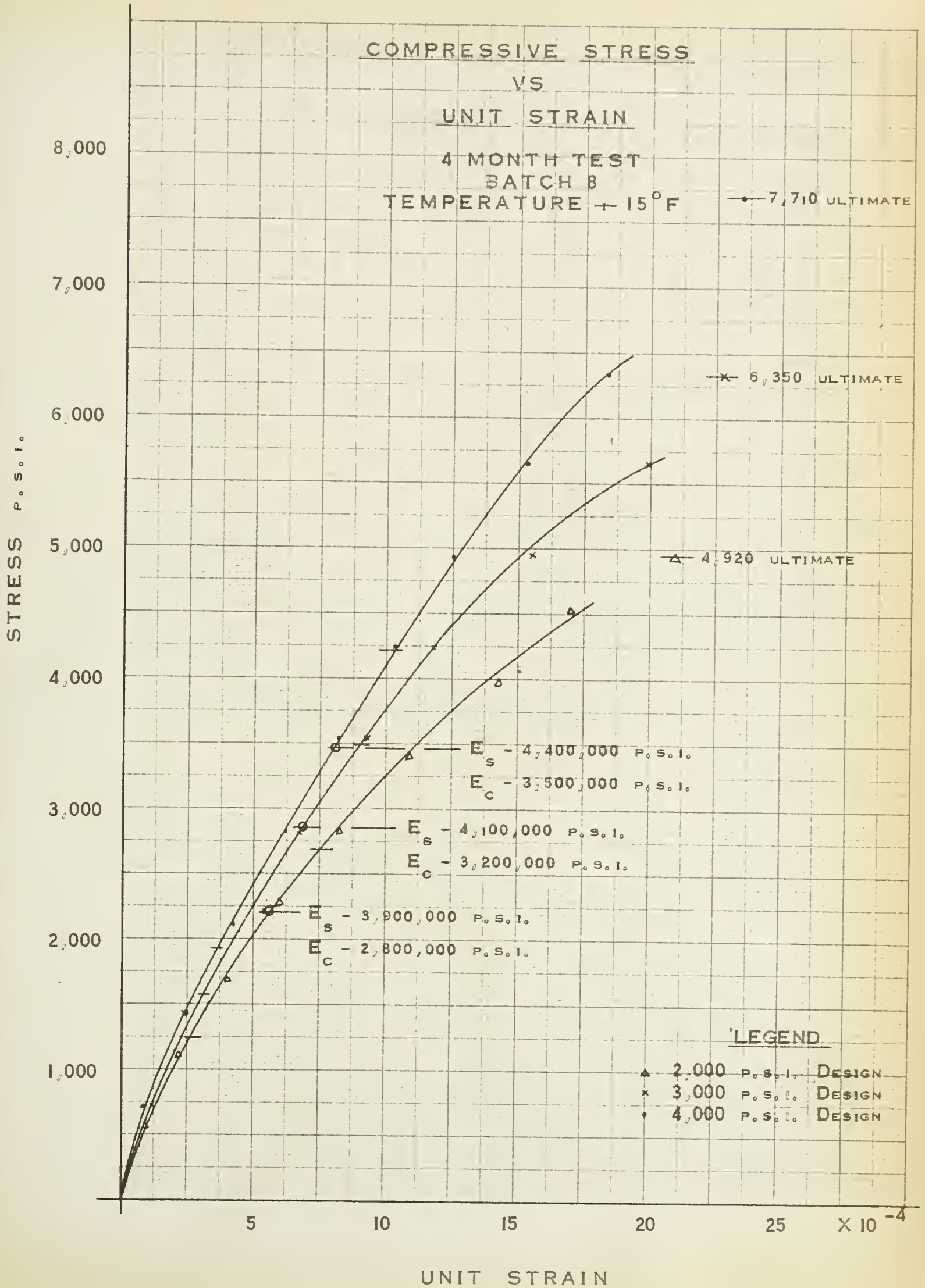












STRESS P. S. I.

COMPRESSIVE STRESS

VS

UNIT STRAIN

4 MONTH TEST

BATCH 3

TEMPERATURE $\pm 31^{\circ}\text{F}$

5,860 ULTIMATE

4,400 ULTIMATE

3,140 ULTIMATE

 $E_C - 3,200,000 \text{ P. S. I.}$ $E_S - 4,000,000 \text{ P. S. I.}$ $E_S - 3,700,000 \text{ P. S. I.}$ $E_C - 2,900,000 \text{ P. S. I.}$ $E_S - 2,900,000 \text{ P. S. I.}$ $E_C - 2,100,000 \text{ P. S. I.}$ LEGEND

- ◆ 2,000 P. S. I. DESIGN
- x 3,000 P. S. I. DESIGN
- 4,000 P. S. I. DESIGN

UNIT STRAIN

4

8

12

16

20

 $\times 10^{-4}$

3,500

3,000

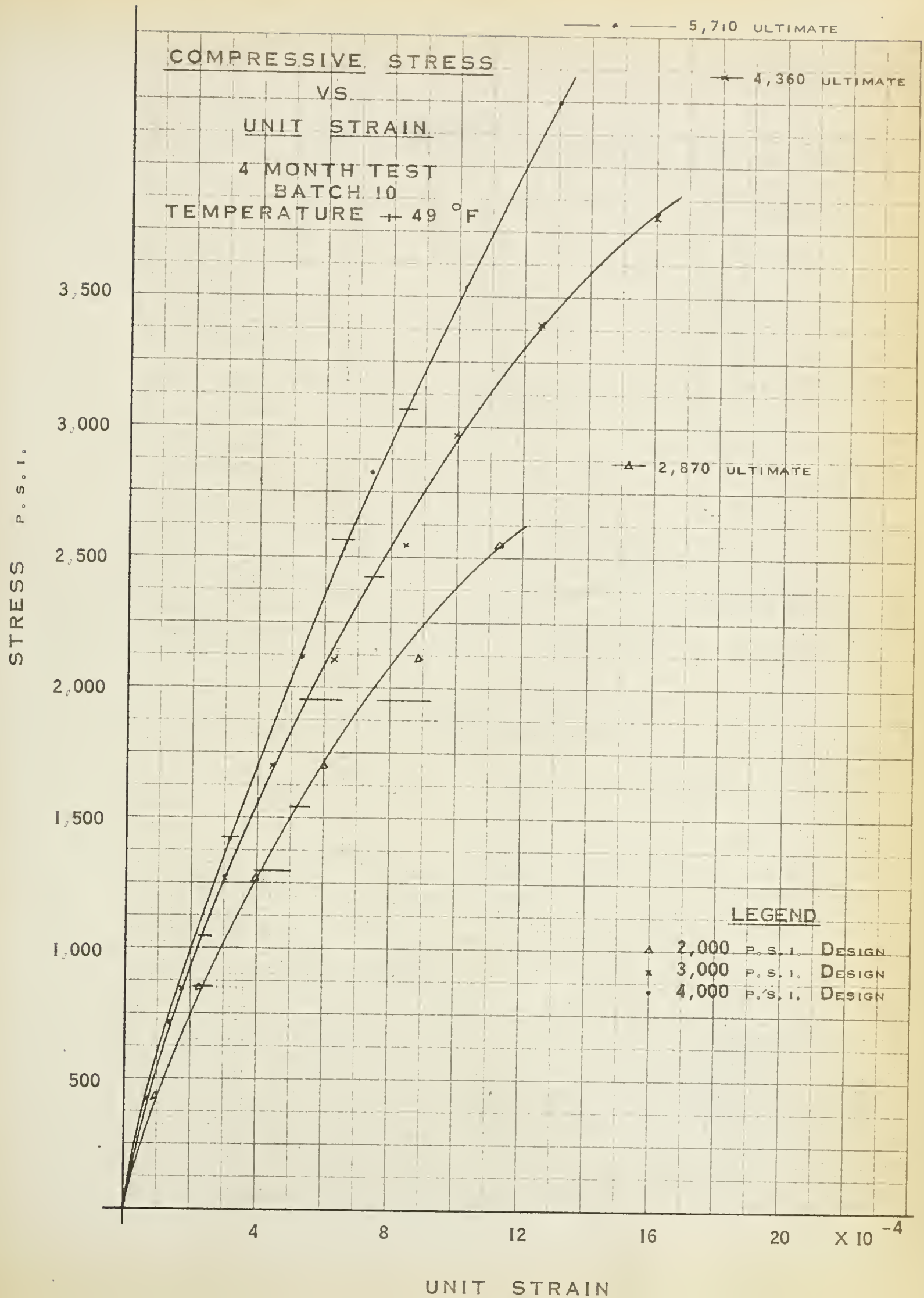
2,500

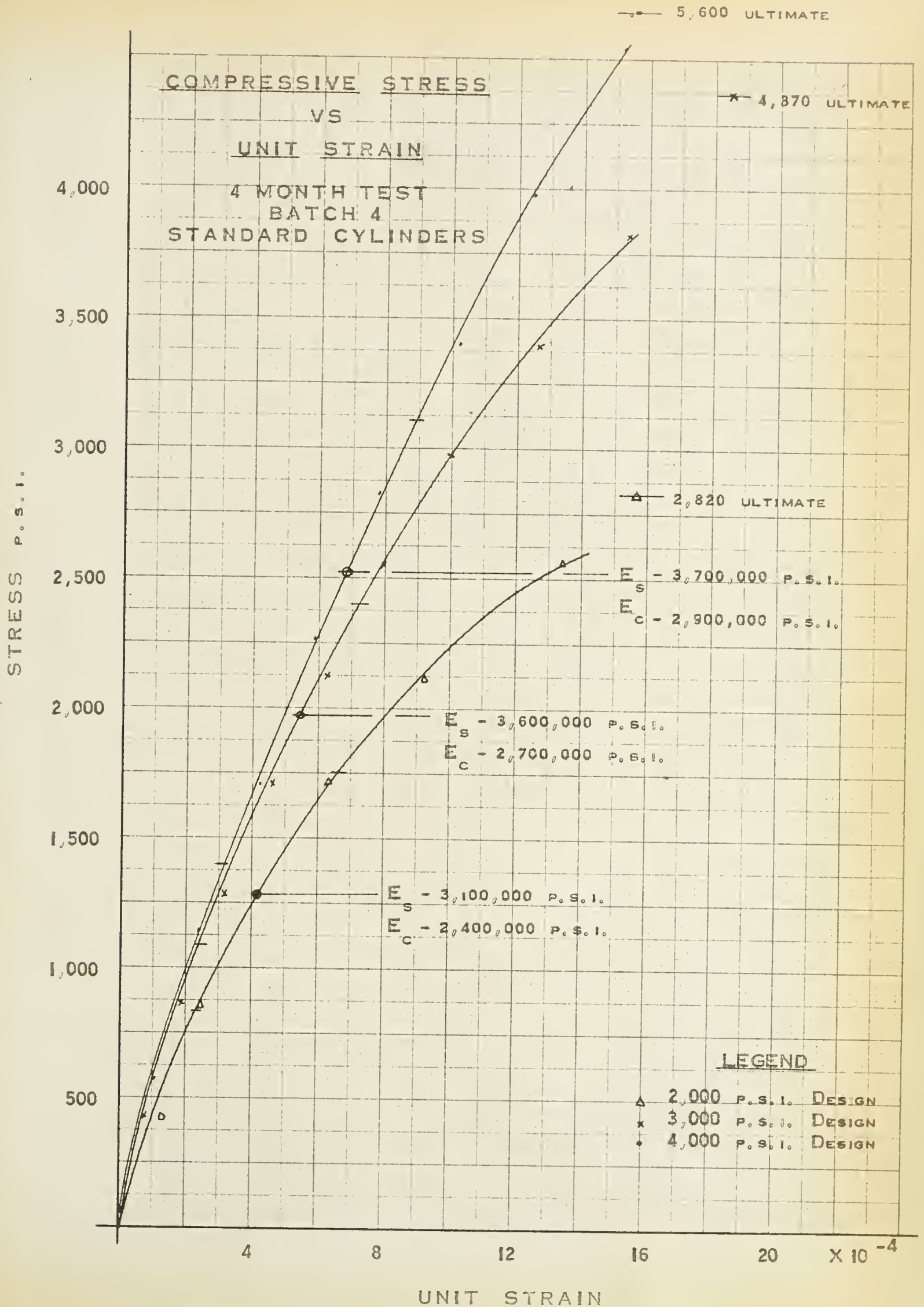
2,000

1,500

1,000

500





B29792